FINAL

Remediation by Natural Attenuation Treatability Study for OU-4 (Site FT-1)

19991021 088

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Shaw Air Force Base
Sumter, South Carolina

Prepared For

Air Force Center for Environmental Excellence
Technology Transfer Division
Brooks Air Force Base, Texas
San Antonio, Texas

and

20 CES/CEVR
Shaw Air Force Base
Sumter, South Carolina

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September 1999

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20 September 1999

Mr. Jerry Hansen
Technical Program Manager
AFCEE/ERT
3207 North Road, Bldg. 532
Brooks AFB, TX 78235-5363

Subject: Submittal of the Final Remediation by Natural Attenuation Treatability Study for OU-4 (Site FT-1), Shaw AFB, South Carolina (Contract F41624-92-D-8036)

Dear Mr. Hansen:

Enclosed please find two copies of the September 1999 Final Remediation By Natural Attenuation Treatability Study for OU-4, Shaw AFB, South Carolina. This report was prepared by Parsons Engineering Science, Inc. (Parsons ES) for the Air Force Center for Environmental Excellence Technology Transfer Division (AFCEE/ERT) and the 20 CES/CEV, Shaw AFB, South Carolina.

The intent of the Natural Attenuation Treatability Study was to determine the role of natural attenuation in remediating chlorinated solvent and fuel contamination in groundwater at OU-4. The draft TS was submitted to AFCEE in May 1998. Comments on the draft TS were received from AFCEE as reviewed by Mr. Jon Atkinson of AFCEE (dated 25 February 1999) and Mr. Richard Roller of 20 CES/CEV (dated 18 March 1999). Responses to these comments were prepared by Parsons ES and are attached to this letter. Your response to our comments as submitted to Parsons ES on 18 August 1999 were addressed and these also are attached to this letter.

If you have any questions or require additional information, please call me at (303) 831-8100.

Sincerely,

PARSONS ENGINEERING SCIENCE, INC.

Bruce M. Henry

Bruce M. Henry, P.G.
Project Manager

Enclosures
c.c. Mr. Rick Roller – Shaw AFB (two copies)
Mr. Don Kampbell – USEPA NRMRL (two copies)

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10 September 1999

Mr. Jerry Hansen
Technical Program Manager
AFCEE/ERT
3207 North Road, Bldg. 532
Brooks AFB, TX 78235-5363

Subject: Responses to *second*-round AFCEE Comments on the Draft Remediation by Natural Attenuation Treatability Study for OU-4 (Site FT-1), Shaw AFB, South Carolina (Contract F41624-92-D-8036-0006)

Dear Mr. Hansen:

This letter provides responses to second-round comments submitted to Parsons ES by the Air Force Center for Environmental Excellence Technology Transfer Division (AFCEE/ERT) regarding the subject report. On 18 June 1999, Parsons ES submitted to AFCEE/ERT the first response to comments letter regarding the TS report for OU-4 at Shaw AFB. AFCEE/ERT reviewed the 18 June 1999 response to comments letter and submitted additional comments/questions on 18 August 1999. Responses to these second round comments were prepared by Parsons ES and are presented herein.

GENERAL COMMENTS

Comment 1) Can the location of the new reactive barrier wall be added to the site maps?

Parsons ES Response: *Placing the position of the reactive barrier wall into the figures would be incongruent with the data shown on most figures. Groundwater data was collected in May 1997 for this project, whereas the reactive barrier walls were installed in 1998. Therefore, the reactive barrier walls have no significance to plume trends prior to installation. For this reason, Parsons ES recommends that the position of the reactive barrier wall not be placed in every figure. Parsons ES does recommend that a figure of the reactive barrier wall location be placed in Appendix E, and referenced through text changes as a result of comments 2 through 4 below.*

Comment 2) Page ES-3. SVE may not be required if the wall works. Recommend that SVE be implemented only if the wall does not adequately reduce the discharge to the creek. There is no guarantee that SVE can clean up the source to a point where we would see a reduction in LTM etc.

Parsons ES Response: *Agreed. Parsons ES concurs that RNA, the permeable reactive barrier wall, and LTM are sufficient to prevent CAH discharge to Long Branch Creek at rates above set regulatory standards. Since natural source weathering will be the only mechanism that will reduce source mass, the duration of an LTM program may continue for decades, although lowered sampling frequencies may be achieved during this period. Section 6 was modified to recommend RNA, LTM, institutional controls, and the continued operation of the permeable reactive barrier wall (modified Alternative 1) versus the implementation of an SVE system (Alternative 2). This change was applied to Page ES-3 to coincide with text revisions in Section 6. Attached pages of the report show page ES-3 and Section 6 text changes in bold.*

Comment 3) Page 6-17. Discussion on funnel and gate may not be relevant if the current existing wall covers the total plume flow. Since the wall is already there it must be considered in the final recommendation. The report can indicate that the analysis of alternatives did not look at a wall, but that the wall was installed under a separate effort.

Parsons ES Response: *Reference to the funnel gate was deleted from page 6-17.*

Comment 4) Page 6-42. SVE may be a consideration down the road if the wall fails etc. Current course of action should be to continue to monitor the site for NA, reactive wall performance, and source area weathering. That may turn out to be all that is needed.

Parsons ES Response: *Agreed. The use of SVE as a contingency action was incorporated into the report as per the response to comment 2.*

Comment 5) Page 8-3. Words indicate a "planned groundwater extraction and treatment system to be installed at the site". Do not indicate that the system is planned. Indicate that a model was used to simulate a P&T only as another alternative.

Parsons ES Response: *Agreed. The referenced sentence was changed to "A third groundwater model was used to simulate the potential effects ~~of the planned~~ **of a** groundwater extraction and treatment system ~~to be installed~~ at the site."*

If you have any questions, have additional comments, or require additional information, please call me at (303) 831-8100.

Sincerely,

PARSONS ENGINEERING SCIENCE, INC.

Bruce M. Henry

Bruce M. Henry, P.G.
Project Manager

cc: Mr. R. Todd Herrington, Parsons ES
File 722450.37000

FINAL
TREATABILITY STUDY IN SUPPORT OF REMEDIATION BY NATURAL ATTENUATION FOR GROUNDWATER AT OU-4 (SITE FT-1)

at

SHAW AIR FORCE BASE
SOUTH CAROLINA

SEPTEMBER 1999

Prepared for:

AIR FORCE CENTER FOR ENVIRONMENTAL EXCELLENCE
TECHNOLOGY TRANSFER DIVISION
BROOKS AIR FORCE BASE
SAN ANTONIO, TEXAS

and

20 CES/CEVR
SHAW AIR FORCE BASE
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ACRONYMS AND ABBREVIATIONS

µg/kg	micrograms per kilogram
ΔG°r	Gibbs free energy of reaction
µg/L	micrograms per liter
1,2-DCE	1,2-Dichloroethylene
ACC	Air Combat Command
AFB	Air Force Base
AFCEE	United States Air Force Center for Environmental Excellence
CAH	chlorinated aliphatic hydrocarbon
CB	chlorobenzene
CPT	Cone Penetrometer
DCA	dichloroethane
DCB	dichlorobenzene
DRO	diesel range organics
ES	Engineering Science
FS/CMS	Feasibility Study/Corrective Measure Study
ft/day	feet per day
ft/ft	foot per foot
HDPE	high density polyethylene
IT	International Technology
IWTP	industrial wastewater treatment plant
LAW	Law Environmental
LIF	laser induced fluorescence
LNAPL	light nonaqueous phase liquid
LTM	long-term monitoring
MCL	maximum contaminant level
mg/kg	milligrams per kilogram
NRMRL	National Risk Management Research Laboratory
ORD	Office of Research and Development
OSWER	Office of Solid Waste and Emergency Response
OU-4	Operable Unit 4
PCA	tetrachloroethane
PCE	tetrachloroethene
POL	petroleum, oils, and lubricants
PVC	polyvinyl chloride
QC	quality control
RAP	Remedial Action Plan
RI/FS	Remedial Investigation/Feasibility Study
RNA	remediation by natural attenuation
Rust E&I	Rust Environment and Infrastucture
SCDHEC	South Carolina Department of Health & Environmental Control
SS	stainless steel
TCA	trichloroethane
TCB	trichlorobenzene
TCE	trichloroethene

TeCB	tetrachlorobenzene
TMB	trimethylbenzene
TS	Treatability Study
USACE	United States Army Corps of Engineers
USEPA	United States Environmental Protection Agency
VC	vinyl chloride

EXECUTIVE SUMMARY

This report presents the results of a treatability study (TS) performed by Parsons Engineering Science, Inc. (Parsons ES) at Operable Unit 4 (OU-4) at Shaw Air Force Base, South Carolina, to evaluate remediation by natural attenuation (RNA) of dissolved chlorinated aliphatic hydrocarbons (CAHs) and fuel hydrocarbons in groundwater. The TS focused on the fate and transport of dissolved CAHs, particularly 1,1,1-trichloroethane (1,1,1-TCA), which is present at high concentrations at the site. Petroleum hydrocarbons [including benzene, toluene, ethylbenzene, and xylenes (BTEX)] also are present in site groundwater and were considered in this TS. The site history and the results of the soil and groundwater investigations conducted previously also are summarized in this report.

Comparison of CAH, BTEX, electron acceptor, and biodegradation byproduct isopleth maps for OU-4 provides strong qualitative evidence of biodegradation of dissolved CAHs. These geochemical data strongly suggest that reductive dehalogenation of dissolved CAHs is occurring at the site as microbes utilize natural organic carbon, BTEX, and other fuel hydrocarbons as substrates. Patterns observed in the distribution of CAHs, daughter products of CAHs, electron acceptors, and biodegradation byproducts also suggest that dehydrohalogenation may be acting to reduce the concentration of CAHs dissolved in site groundwater. Field-scale, first-order decay rates computed using data from OU-4 include a total BTEX biodegradation rate of 0.014 day^{-1}, a total chlorinated ethene decay rate of 0.012 day^{-1}, a total chlorinated ethane decay rate of 0.013 day^{-1}, and a dichlorobenzene decay rate of 0.011 day^{-1}. The equivalent half-lives are 50 days, 56 days, 53 days, and 61 days, respectively. The computed rate of reductive dechlorination for total chlorinated ethene and ethane contamination is 0.0026 day^{-1} (half-life of 266 days) and 0.0025 day^{-1} (half-life of 213 days), respectively.

An important component of this study was an assessment of the potential for contamination in groundwater to migrate from the source areas to potential receptor exposure points (i.e., stretches of creeks or ponds downgradient or downstream from the source). The finite-difference models MODFLOW and MT3D96® were used in conjunction with site-specific geologic, hydrologic, and laboratory analytical data to simulate the migration and biodegradation of CAHs dissolved in groundwater. Model parameters that were not measured at the site were estimated using reasonable literature values.

The results of this demonstration indicate that RNA of dissolved CAHs and BTEX contamination is occurring at OU-4. Conservative modeling suggests that under current conditions, the CAH plume is at steady-state, and dissolved CAHs will continue to migrate from the source area to the edge of Long Branch Creek that borders OU-4 to the east. The estimated rates of biodegradation combined with the effects of sorption, dispersion, and dilution result in a two-order-of-magnitude reduction in dissolved CAH concentrations between the source area and Long-Branch Creek. CAH concentrations discharging to Long Branch Creek are significantly lower than source area concentrations, and appear to have minimal impact on surface water quality. Maximum groundwater CAH concentrations coincide with the presence of observed light non-aqueous phase liquid (LNAPL) in monitoring points installed at OU-4. Therefore,

model results indicate the importance of source removal to assist natural attenuation processes for site remediation.

Future site activities are not anticipated to change, and the risk to any Base personnel would be minimal, provided institutional controls for soil and groundwater content are maintained. Institutional controls such, as restrictions on shallow groundwater and surface water use at the site would prevent completion of receptor exposure pathways until RNA is complete.

A permeable reactive barrier wall (iron filings trench) was installed in November 1998 to mitigate the migration of contaminants to Long Branch Creek to the east of OU-4. The permeable reactive barrier wall is a passive technology intended to degrade dissolved contaminants migrating from the site. The primary focus of this TS is to evaluate the use of RNA, both alone and in combination with engineered remedial actions, to minimize LTM periods and remediation costs. Based on the evaluation of site contamination at OU-4, the Air Force Center for Environmental Excellence (AFCEE) recommends implementation of RNA, long-term monitoring (LTM), institutional controls, and continued operation of the permeable reactive barrier wall.

To verify model predictions, and to ensure that the selected technologies are meeting objectives, the Air Force recommends using periodic sampling of 11 LTM wells, 1 sentry well, and 6 surface water locations to monitor the long-term migration and degradation of the dissolved CAH plume. In addition to analyses used to verify the effectiveness of RNA, the groundwater samples should be analyzed for CAH and BTEX compounds by US Environmental Protection Agency (USEPA) Method SW8260b or SW8021b. If data collected under the LTM program indicate that the selected remedial alternative is not sufficient to reduce CAH concentrations, specifically 1,1,1-TCA concentrations, at downgradient well locations to levels considered protective of human health and the environment, additional corrective actions may be required to remediate groundwater at the site.

SECTION 1

INTRODUCTION

This report presents the results of a treatability study (TS) conducted to evaluate the potential effectiveness of remediation by natural attenuation (RNA) for groundwater contaminated with several types of chlorinated aliphatic hydrocarbons (CAHs) and petroleum hydrocarbons at the Former Fire Training Area 1, Operable Unit 4 (OU-4) at Shaw Air Force Base (AFB) in Sumter, South Carolina. As used in this report, RNA refers to a management strategy that relies on natural attenuation mechanisms to remediate contaminants dissolved in groundwater and to control receptor exposure risks associated with contaminants in the subsurface. The United States Environmental Protection Agency (USEPA) Offices of Research and Development (ORD) and Solid Waste and Emergency Response (OSWER) define natural attenuation as (Wilson, 1996):

The naturally occurring processes in soil and groundwater environments that act without human intervention to reduce the mass, toxicity, mobility, volume, or concentration of contaminants in those media. These in-situ *processes include biodegradation, dispersion, dilution, adsorption, volatilization, and chemical or biological stabilization or destruction of contaminants.*

As suggested by this definition, mechanisms for natural attenuation of CAHs include advection, dispersion, dilution from recharge, sorption, volatilization, abiotic chemical transformation, and biodegradation. Of these processes, biodegradation is the most common mechanism working to transform contaminants into innocuous byproducts. During natural biodegradation, indigenous microorganisms work to bring about a reduction in the total mass of contamination in the subsurface without artificial intervention (e.g., addition of nutrients). Patterns and rates of natural attenuation can vary markedly from site to site depending on governing physical and chemical processes.

1.1 SCOPE AND OBJECTIVES

Parsons ES was retained by the United States Air Force Center for Environmental Excellence (AFCEE) Technology Transfer Division to conduct site characterization and groundwater modeling to evaluate the scientific defensibility and technical feasibility of RNA with long-term monitoring (LTM) as a remedial option for fuel- and industrial-solvent- contaminated groundwater at OU-4. Site characterization activities conducted at OU-4 as part of this study consisted of numerous tasks that were required to fulfill the project objective. These tasks included:

- Reviewing existing hydrogeologic and soil and groundwater quality data for the site;
- Conducting supplemental site characterization activities to more thoroughly characterize the nature and extent of groundwater contamination;
- Collecting geochemical data in support of RNA;
- Developing a conceptual hydrogeologic model of the shallow saturated zone, including the current distribution of contaminants;
- Evaluating site-specific data to determine whether natural contaminant attenuation and destruction are occurring in groundwater at the site;
- Designing and executing a groundwater flow and contaminant fate and transport model for site hydrogeologic conditions;
- Simulating the fate and transport of the total chlorinated solvent plume (e.g., chlorinated ethenes, ethanes and benzenes) in groundwater under the influence of advection, dispersion, adsorption, and biodegradation using the calibrated model;
- Evaluating a range of model input parameters to determine the sensitivity of the model to those parameters and to consider several contaminant fate and transport scenarios;
- Determining if natural processes are minimizing plume expansion of dissolved contaminants so that groundwater and surface water quality standards can be met downgradient;
- Conducting an exposure pathways analysis for potential current and future receptors; and
- Using the results of modeling to determine the adequacy of RNA to protect human health and the ecosystem and to formulate a LTM plan.

A two-phase site characterization effort was conducted to collect the data necessary to support RNA at OU-4. Phase I site characterization activities were completed on April 3-4, 1997, and involved the exploration of the subsurface with cone penetrometer testing (CPT) and laser-induced fluorescence (LIF) equipment, and placement of five groundwater monitoring points (MPA through MPE). Phase II site characterization was completed from May 14 through 18, 1997, and involved installation of six additional monitoring points (TMP 1 through TMP 6); reinstallation of monitoring point MPE with a Geoprobe®; groundwater sample collection from site monitoring wells and points; surface water and sediment sample collection from site surface water bodies; analysis of groundwater, surface water and sediment samples; collection and analysis of mobile light nonaqueous-phase liquid (LNAPL, or free product) from site monitoring points; aquifer testing; and static groundwater level measurement. Field investigation methods are described in the TS Work Plan (Parsons ES, 1997).

Site-specific data collected during the May 1997 field investigation were used to develop a groundwater flow and solute fate and transport model for the site and to conduct a preliminary exposure pathways analysis. The model was used to predict the future extent and concentrations of dissolved CAH and chlorinated aromatic hydrocarbon plumes by simulating the combined effects of advection, dispersion, sorption, and biodegradation. Results of the model were used to predict future discharge to surface water, to assess the potential for completion of other exposure pathways involving groundwater, and to identify whether natural attenuation with LTM is an appropriate and defensible remedial option for contaminated groundwater.

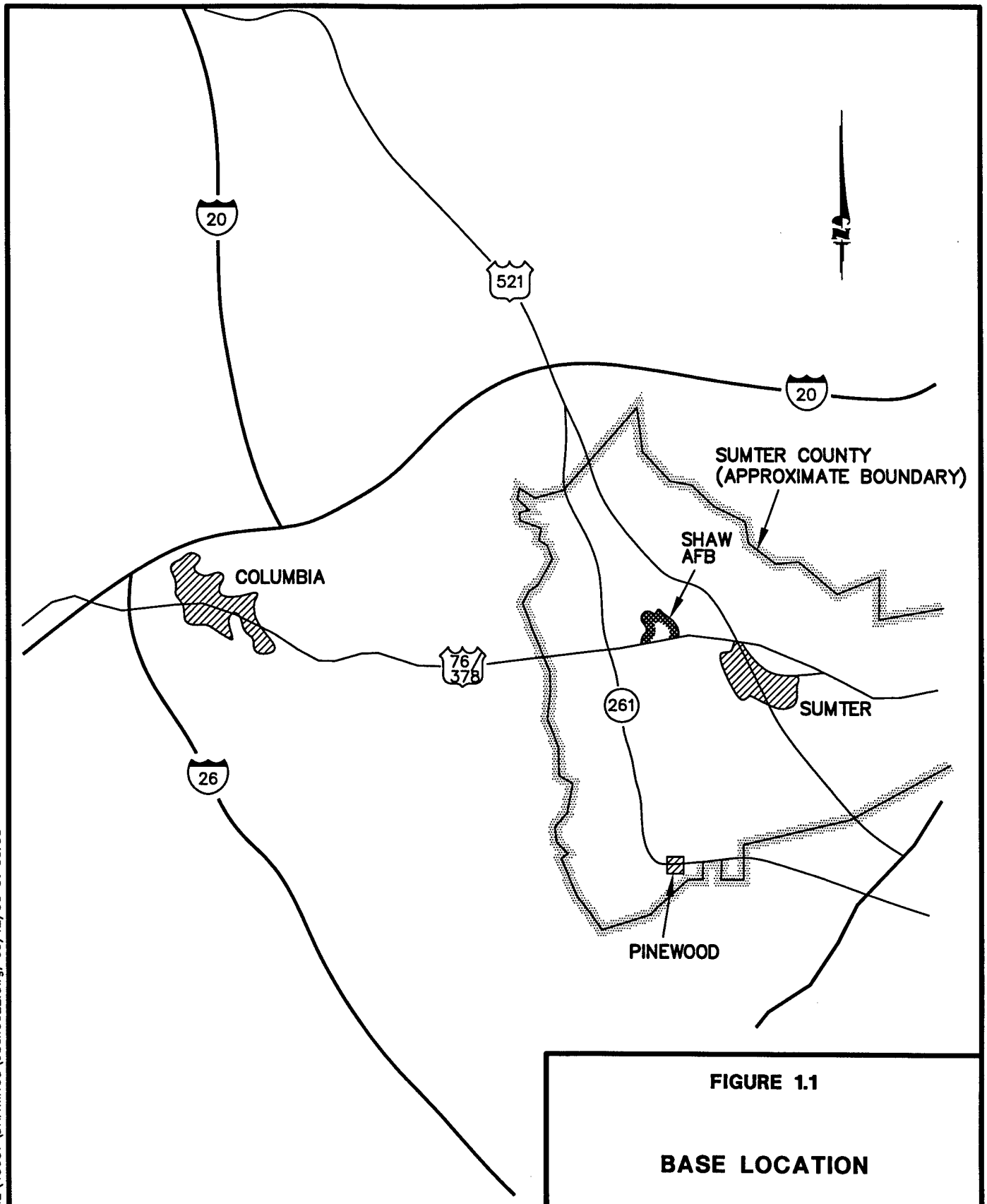
This report is intended to be used by the Base, the US Army Corps of Engineers (USACE), the USEPA, the South Carolina Department of Health and Environmental Control (SCDHEC), and other agencies responsible for establishing and approving a site closure plan. Specifically, the results presented herein can be used to justify the future role of RNA with LTM in site remediation, either as the sole remediation alternative or in conjunction with engineered remedial alternatives proposed in the feasibility study/corrective measures study (FS/CMS) for the site [Rust Environment & Infrastructure (Rust E&I), 1996].

1.2 REPORT ORGANIZATION

This TS contains nine sections, including this introduction, and four appendices. Section 2 summarizes site characterization activities. Section 3 summarizes the physical characteristics of the study area. Section 4 describes the nature and extent of soil, groundwater, surface water, and sediment contamination, and the geochemistry of soil and groundwater at the site. Section 5 describes the design of the conceptual hydrogeologic model and numerical groundwater flow and contaminant fate and transport model for the site; lists model assumptions and input parameters; and describes sensitivity analyses, model output, and the results of the modeling. Section 6 presents a comparative analysis of remedial alternatives, and Section 7 presents the LTM plan for the site. Section 8 presents the conclusions of this work and provides recommendations for further work at the site. Section 9 lists the references used to develop this document. Appendix A contains borehole logs, CPT/LIF results, monitoring well construction diagrams, monitoring well/point sampling forms, aquifer test results, and survey data. Appendix B presents soil, sediment, groundwater, and surface water analytical results collected as part of this TS. Appendix C contains model input parameters, model output and supporting figures, and calculations related to model calibration. Appendix D contains model input files. Appendix E contains cost calculations pertinent to remedial alternatives selection. Appendix F contains a figure of the iron filings wall installed in November 1998 at Site S-1. Appendix G contains review comments and responses for this report.

1.3 INSTALLATION DESCRIPTION AND HISTORY

Shaw AFB is located near the center of South Carolina in northwest Sumter County, approximately 37 miles east of Columbia and 7 miles west of the city of Sumter along US Highway 76 (Figure 1.1). The Base encompasses 3,326 acres of land set in a mostly rural and agricultural area; however, residential and commercial developments are present in the western and southeastern parts of the Base (Rust E&I, 1995).



Source: RUST E&I, 1996.

FIGURE 1.1

BASE LOCATION

OU-4 RNA TS
Shaw AFB, South Carolina

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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Established as an Air Force flying school in 1941, the Base was under the Tactical Air Command. Numerous aircraft changes have since occurred at the Base, but the mission has always been to provide tactical fighter forces. To support this mission, quantities of petroleum, oils, and lubricants (POL); solvents; and coatings were used, resulting in waste generation. The host organization for the Base is the 20th Fighter Wing, which has three F-16 Squadrons. In addition, several tenant units are located at the Base. The Base and its fighter wing are now under the Air Combat Command (ACC).

1.4 OU-4 BACKGROUND

OU-4 encompasses the area impacted by activities at Former Fire Training Area 1. The site consists of approximately 14 acres located between Patrol Road on the west and Long Branch Creek (a surface water drainage along the east-northeastern Base property boundary) on the east (Figures 1.2 and 1.3). The remnants of a berm provide evidence of a former burn pit; however, interpretation of historical aerial photographs suggests that the fire pit was moved periodically during the operation of the facility (Rust E&I, 1995). The site features sparse vegetation except in the heavily wooded perimeter and on the slopes near Long Branch Creek.

Reportedly, the former fire training area was used for weekly fire training exercises from 1941 until 1969. A variety of combustible wastes were burned during the training exercises, including jet fuel, waste oils, hydraulic fluids, spent solvents, contaminated fuels, and napalm. Waste materials were hauled to the site in drums and poured into unlined burn pits for ignition. Extinguishing agents reportedly used during training exercises included water, carbon dioxide, protein foam, and aqueous-film-forming foam. Some of the drums used to store and transport the combustibles may have been buried at the site (Parsons ES, 1994; Rust E&I, 1995).

The fire training area was first identified as having a "high potential for environmental contamination" in a 1983 Phase I assessment [Engineering-Science, Inc. (ES), 1983). Since the initial Phase I assessment, numerous remedial activities have been performed at the site; these activities are summarized in Table 1.1 and discussed below. A Phase II, Stage I investigation was performed by Research Triangle Institute (RTI, 1986) in January 1986 and a Stage II investigation was performed by Law Environmental, Inc. (Law, 1989) between July 1986 and February 1987. A remedial action plan (RAP) was prepared by Law (1989) to identify, evaluate, and recommend remedial action alternatives that would address the contamination at the site. At that time, a groundwater monitoring program was selected as the alternative capable of providing the appropriate level of protection to the environment and public health at the most reasonable cost. After collection of two years of quarterly groundwater monitoring data (1988 - 1990), it was decided that long-term monitoring did not adequately address site remediation and that additional investigations were warranted. Since reopening the investigation, Law (1991) prepared a draft remedial investigation (RI)/FS, and Rust E&I (1995) conducted supplemental RI activities and issued the final RI report.

TABLE 1.1
HISTORY OF PAST REMEDIAL ACTIVITIES AT OU-4
OU-4 RNA TS
SHAW AFB, SOUTH CAROLINA

Activity	Report/Reference	Results/Recommendations
Identify contaminated Sites Shaw AFB	Installation Restoration Program (IRP), Phase I (Engineering Science, 1983)	OU-4 was identified as having "high potential for environmental contamination" during Phase 1 study. Site recommended for Phase II investigation to provide more specific contaminant information.
Verify the presence of site contamination at OU-4	IRP, Phase II, Stage I (RTI, 1986)	Four wells installed at OU-4 (MW-105, -106, -107, and -111, see Figure 1.3) to measure potential downgradient and background contaminant concentrations. Analytical data verified that the shallow aquifer had been impacted by oil and grease, total organic halogens, and various volatile organic compounds (VOCs).
Further delineate soil and groundwater contamination at OU-4	IRP, Phase II, Stage II; July 1986 to February 1987 (Law, 1989)	On the basis of Phase II, Stage 1 information, Law Environmental installed five shallow monitoring wells (MW-112, -113, -113A, -114, and -115), three deep (Black Creek Aquifer) wells (MW-105D, -106D, and -112D), a pump test well (TW-101); and three observation wells (PZ-101, -102, and -103); two surface water and sediment locations (SW/SD-11 and -12); and one soil boring within the fire pit berm (SB-111). Soil data indicated that total recoverable petroleum hydrocarbon (TRPH) and lead contamination occurred primarily in the vadose zone beneath the fire training pit. A pump test was performed at TW-101 using observation wells PZ-101, -102, and -103.
Perform quarterly groundwater and surface water monitoring at OU-4	Phase II sampling; 1988 through 1990 (Law, 1989 and 1991).	Shallow aquifer determined to be contaminated with benzene, toluene, ethylbenzene, and xylenes (BTEX), chlorinated solvents, and metals. Two surface water stations (SW-1-3 and SW1) were included in the quarterly monitoring program. BTEX compounds in groundwater and saturated sediments indicated that contaminants had migrated from source area to Long Branch Creek. No VOCs other than methylene chloride were detected in surface water.

TABLE 1.1 (Continued)
HISTORY OF PAST REMEDIAL ACTIVITIES AT OU-4
OU-4 RNA TS
SHAW AFB, SOUTH CAROLINA

Activity	Report/Reference	Results/Recommendations
Identify, evaluate, and recommend remedial actions	Remedial Action Plan (Law, 1989)	On the basis of Phase II site data, groundwater monitoring selected as the most viable remedial action alternative. A 2-year monitoring program implemented, after which it was decided that groundwater monitoring alone was insufficient to remediate the site.
Soil gas survey at OU-4	Phase II sampling (Law, 1989).	Law Environmental conducted a soil gas survey at 40 shallow soil-gas monitoring stations. The survey results indicated an elongated area of soil contamination stretching in a northwest/southeast direction and intersecting the fire training pit.
Reevaluate the proposed remedial actions	Draft RI/FS (Law, 1991)	Monitoring program results indicated possible contaminant migration in the shallow aquifer from the source area to Long Branch Creek. No surface water or sediment samples exhibited elevated site contaminants. Recommended the use of collection systems to halt contaminated groundwater before migrating to Long Branch Creek. Site officially named under the Resource Conservation and Recovery Act (RCRA) and officially named OU-4 under a separate Interim RCRA Facility Assessment (RFA) report.
Address remaining data gaps	Supplemental RI/FS work plan (SEC Donohue, Inc., 1992)	Performed topographic and geophysical surveys of the study area; recommended soil quality assessment in soil gas "hot spots"; installed additional monitoring wells (MW-116, -116A, -112A, -115A, -117, -118, and -119A); evaluated the hydrologic characteristics of the shallow aquifer; collected additional surface water and sediment sampling; performed a soil vapor extraction (SVE)/bioremediation treatability study; and performed data validation.
Perform soil SVE pilot test and bench scale bioremediation study	Draft Final Soil Vapor Extraction and Bioremediation Study Report (Rust E&I, 1993)	SVE pilot test and bioremediation study performed to aid in the selection of soil remediation alternatives for OU-4 as part of the RI/FS. SVE pilot test results indicated that the zone of influence for both vertical and horizontal SVE systems was limited. The bench-scale bioremediation study was performed on contaminated vadose soils at the site. The study indicated significant microbial activity on the basis of oxygen uptake and carbon dioxide evolution; however total petroleum hydrocarbon (TPH) and diesel-range organics (DRO) concentrations did not appear to decrease. Water and oxygen addition (e.g., through bioventing) were recommended for remediation of vadose soils on the basis of the bioremediation study.

TABLE 1.1 (Concluded)
HISTORY OF PAST REMEDIAL ACTIVITIES AT OU-4
OU-4 RNA TS
SHAW AFB, SOUTH CAROLINA

Activity	Report/Reference	Results/Recommendations
Perform soil bioventing pilot test within fire training pit	Initiated 11/18/94; Streamlined test (AFCEE, 1996)	Bioventing test results indicate that TRPH and BTEX compounds were reduced between 1 to 3 orders-of-magnitude at the site. Successful hydrocarbon reductions through bioventing prompted the recommendation to continue bioventing at the discretion of the Base. The bioventing system continues to operate at the time of this report.
Perform chemical oxidation pilot test	Initiated 11/11/96; (IT, 1997)	Chemical oxidation pilot test performed to determine if groundwater contamination at OU-4 can be treated and reduced using hydrogen peroxide and ferrous iron (Fenton's reagent). Results indicated the generally uniform reductions of aromatic and chlorinated aliphatic hydrocarbons within an estimated effective treatment radius of 30 feet from the injection well. Off-gas of oxygen by *in situ* chemical reactions, dilution effects, and soil heterogeneity complicated quantifying the remedial effect of chemical oxidation. A full-scale chemical oxidation treatment system was recommended.
Groundwater pump and treat	None available.	At the time of this report, a groundwater pump-and-treat system is planned for the site as an interim measure (IM) under the direction of IT Corporation in an attempt to minimize plume migration and discharge to Long Branch Creek while the option of monitored natural attenuation is evaluated.

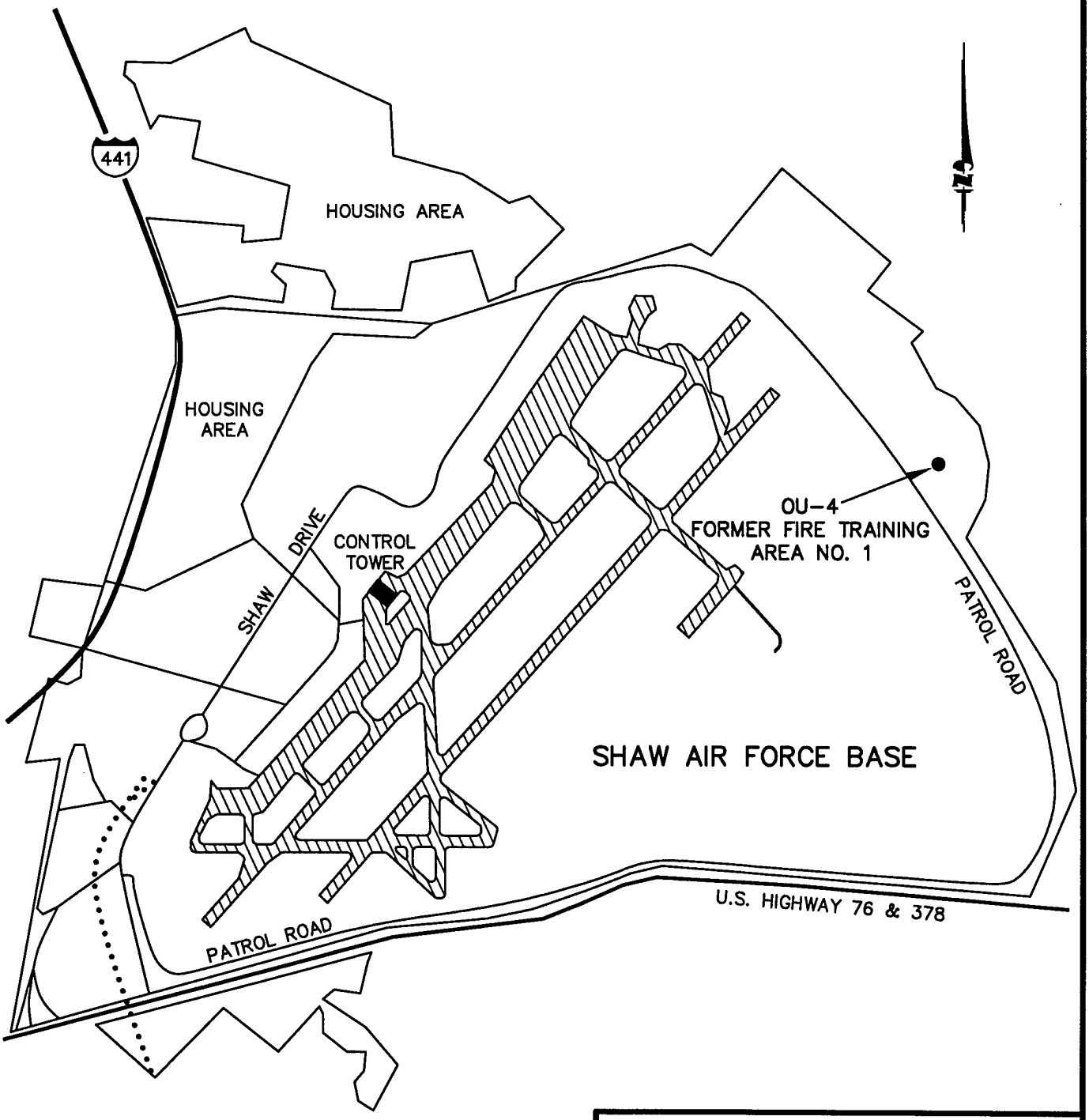

FIGURE 1.2

SITE LOCATION

OU-4 RNA TS
Shaw AFB, South Carolina

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

Source: RUST E&I, 1996.

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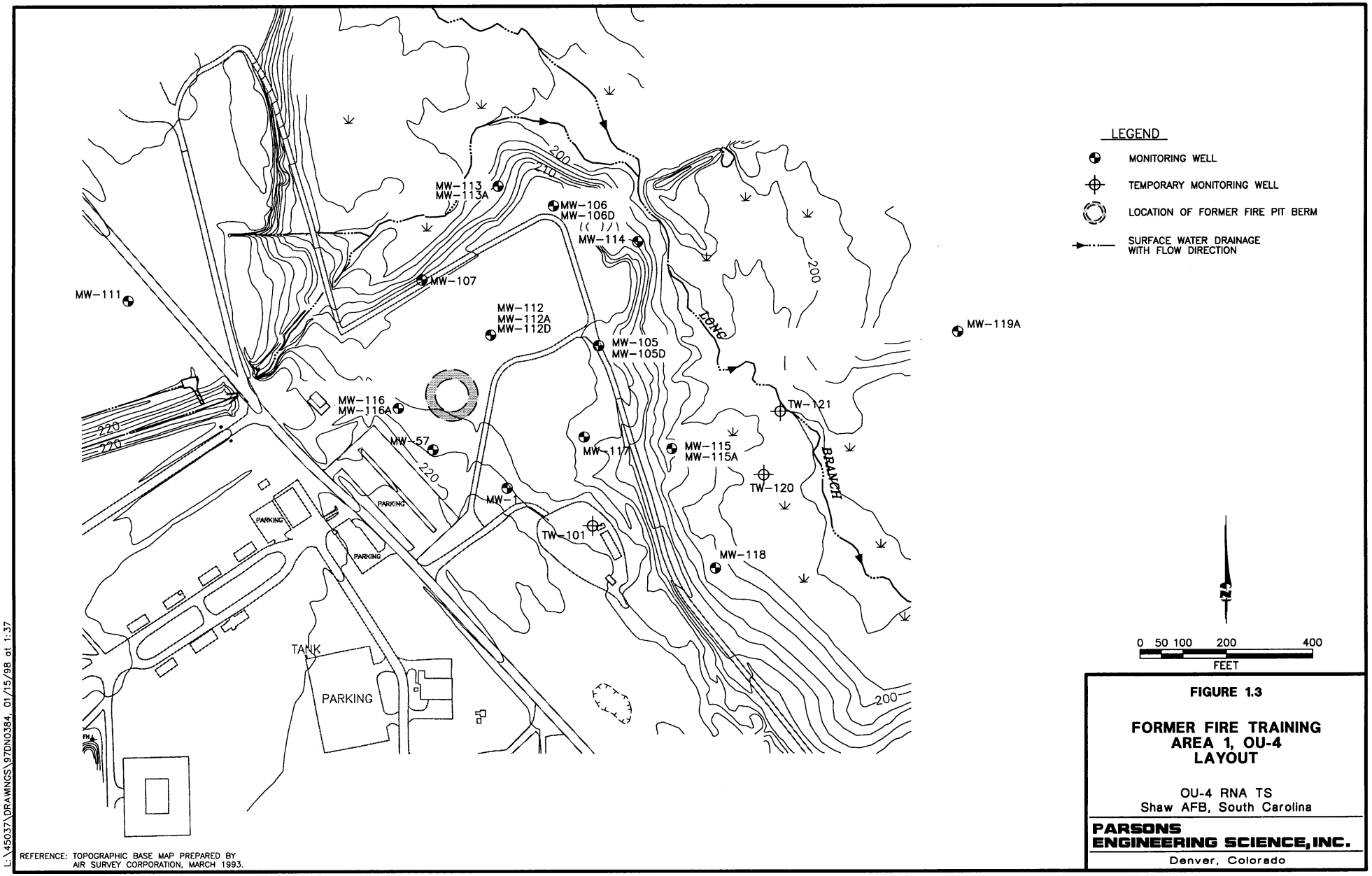

REFERENCE: TOPOGRAPHIC BASE MAP PREPARED BY AIR SURVEY CORPORATION, MARCH 1993.

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FIGURE 1.3

FORMER FIRE TRAINING AREA 1, OU-4 LAYOUT

OU-4 RNA TS
Shaw AFB, South Carolina

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

Beginning with the supplemental RI activities at the fire training area, the applicability of several remedial alternatives has been evaluated through pilot tests and bench-scale studies. The majority of these activities have focused on soils in the vicinity of the former (bermed) burn pit. Rust E&I (1993) conducted short-duration soil vapor extraction (SVE) pilot tests in the former bermed burn pit in 1993 to collect data for full-scale design, to monitor oxygen-enhanced respiration rates of indigenous microorganisms, and to compare the operating effectiveness of horizontal SVE wells versus vertical SVE wells. Success was limited due to vent well construction designs that contributed to air short-circuiting and soil water recovery (Rust E&I, 1993). A laboratory bench-scale study, also performed in 1993, concluded that a significant population of indigenous microorganisms is present in contaminated site soils, and rapid growth was exhibited by the microbes when supplied with oxygen (Rust E&I, 1993). In 1994, Parsons ES (1994 and 1995) performed a bioventing pilot test in a portion of the former bermed burn pit unaffected by the SVE system. After 1 year, soil concentrations of benzene, toluene, ethylbenzene, and xylenes (BTEX) decreased 1 to 3 orders of magnitude within approximately 30 feet of the air injection vent wells (Parsons ES, 1996). The bioventing pilot system has remained in operation in order to continue remediation of the heavier hydrocarbons in soils within the former bermed burn pit.

The most recent pilot test, conducted in November 1996, addressed chlorinated solvent contamination dissolved in groundwater in the vicinity of monitoring well MW-117, where the highest historical concentrations of dissolved chlorinated solvents have been detected at OU-4 [International Technology Corporation (IT), 1997]. The pilot test attempted to stimulate chemical oxidation through the one-time injection of hydrogen peroxide, sulfuric acid, and ferrous sulfate. The study concluded that approximately 80 percent of mass removal was attributed to stripping, with the remaining 20 percent attributed to chemical oxidation. This rate of chemical oxidation was approximately 35 percent of the anticipated chemical oxidation rate. Once again, these estimates were based on results collected one week after injection, and information regarding the long-term chemical oxidation effects is currently unavailable. The cost to remediate site groundwater using hydrogen peroxide injection was estimated at approximately 2.5 million dollars (IT, 1997).

1.5 SITE INVESTIGATION REPORTS

The results of previous site investigations are presented in the following reports:

- Installation Restoration Program, Phase I: Records Search, Shaw AFB, South Carolina (ES, 1983);
- Installation Restoration Program, Phase II: Confirmation 1 Quantification Stage 1, Shaw AFB, South Carolina (RTI, 1986);
- Remedial Action Plan, Shaw Air Force Base (Law, 1989);
- Draft Remedial Investigation and Feasibility Study Report for Site 1 - Former Fire Training Area No. 1, Shaw AFB, Sumter, SC. Prepared for the US Army Corps of Engineers (Law, 1991);

- Draft Soil Vapor Extraction and Bioremediation Study Report (RUST E&I, 1993);
- Bioventing Test Work Plan for IRP Site FT-01 (Former Fire Training Area 1) and IRP Site SS-15 (POL Fuel Depot), Shaw AFB (Parsons ES, 1994);
- Draft Interim Bioventing Pilot Test Results Report, IRP Site FT-01 (Former Fire Training Area 1) and IRP Site SS-15 (POL Fuel Depot) Shaw AFB, SC (Parsons ES, 1995);
- Soil Vapor Extraction and Bioremediation Study Report, Operable Unit #4 (Rust E&I, 1993);
- Final RI Report, Operable Unit #4, Former Fire Training Area No. 1, IRP Site No. FT-1, Shaw AFB, SC (Rust E&I, 1995);
- Memorandum to Mr. Randy Adams, 20 CES/CEV, Kelly AFB, Re: Completion of Final Bioventing Test, Shaw AFB, Site FT-01 (Former Fire Training Area 1) and Site SS-15 (POL Fuel Depot) (Parsons ES, 1996);
- Final Feasibility Study/Corrective Measures Study Report and Proposed Plan, Operable Unit #4, Former Fire Training Area No. 1 (IRP Site No. FT-1, SWMU#59) (Rust E&I, 1996); and
- Draft Chemical Oxidation Pilot Test Report, Operable Unit 4, IRP Site Number FT-01, Shaw AFB, SC, Contract No. DACW 45-93-D-0044, TERC Region 2, Delivery Order 0004, AF Project No. VLSB-95-7002 (IT, 1997).

The site-specific data presented in Sections 3, 4, and 5 are based on a review of these documents and on data collected by Parsons ES under this program in April and May 1997.

SECTION 2

SITE CHARACTERIZATION ACTIVITIES

To meet the requirements of the RNA TS, additional data were required to evaluate near-surface geology and hydrogeology, contaminant distribution, and groundwater geochemistry. Site characterization activities involved borehole advancement and groundwater monitoring point installation with a cone penetrometer or Geoprobe®; collection of groundwater samples from existing monitoring wells and newly installed monitoring points; collection of surface water and sediment samples from adjacent creeks; and performance of slug tests on select groundwater monitoring wells. The scope of these activities is described in the work plan for this RNA TS (Parsons ES, 1997), and the work was performed in April and May 1997.

The physical and chemical data listed below were collected during the field work phase of the TS:

- Depth from measurement datum to the water table or potentiometric surface in monitoring wells and points;
- Stratigraphy of subsurface media;
- Groundwater geochemical data, including pH, temperature, electrical conductivity, total alkalinity, oxidation-reduction potential (ORP), dissolved oxygen (DO), carbon dioxide, chloride, nitrate+nitrite as nitrogen (N), ammonia, ferrous iron, manganese, sulfate, total organic carbon (TOC), dissolved hydrogen, and methane/ethane/ethene;
- Concentrations of CAHs, aromatic volatile organic compounds (VOCs) (including chlorinated benzenes), and metals in groundwater;
- Concentrations of CAHs and aromatic VOCs in surface water.

The following sections describe the procedures that were followed when collecting site-specific data. Additional details regarding investigative activities are presented in the work plan (Parsons ES, 1997).

2.1 CONE PENETROMETER TESTING

2.1.1 Monitoring Point Placement and Investigation of Site Stratigraphy with CPT

A cone penetrometer was used to install monitoring points at five locations at OU-4, identified as monitoring points MPA through MPE, on April 3 and 4, 1997.

Monitoring MPE was abandoned due to incorrect placement and reinstalled in May 1997 (using the same designation) with a Geoprobe® (Section 2.2) approximately 125 feet northeast of its former location. The CPT activities were conducted by the US Army Corps of Engineers (USACE). The cone penetrometer consists of an instrumented probe that is forced into the ground using a hydraulic load frame mounted on a heavy truck, with the weight of the truck providing the necessary reaction mass. The penetrometer equipment is housed in a stainless steel, dual-compartment body mounted on a 43,000-pound, triple-axle Kenworth® truck chassis powered by a turbo-charged diesel engine. The weight of the truck and equipment is used as ballast to achieve the overall push capability of 39,000 pounds.

The penetrometer probe has a 1.8-inch outside-diameter (OD), 60-degree conical point with sacrificial tip, and an 8.0-inch-long by 1.8-inch-OD friction sleeve. Inside the probe, two load cells independently measure the vertical resistance against the conical tip and the side friction along the sleeve. Each load cell is a cylinder of uniform cross-section that is instrumented with four strain gauges in a full-bridge circuit. As the probe is pushed into the subsurface, resistive forces are sensed by the load cells, and the data are transmitted from the probe assembly via a cable running through the push tubes. The analog data are digitized, recorded, and plotted by computer in the penetrometry truck to provide soil stratigraphy data.

After collecting soil stratigraphy data or placing a monitoring point (Section 2.3) with the cone penetrometer, the push rods were cleaned during extraction with the CPT steam-cleaning system (rod cleaner) as they were withdrawn from the ground. A vacuum system located beneath the cone penetrometer truck was used to recover cleaning water. Use of this system resulted in nearly 100-percent recovery of steam-cleaning rinseate from the rod cleaner. Precautions were taken to minimize any impact to the surrounding area that might result from decontamination operations. Potable water used in CPT equipment cleaning and decontamination was obtained from the Base water supply.

2.1.2 Investigation of Residual and Mobile Hydrocarbons

The known propensity of aromatic hydrocarbons to fluoresce under ultraviolet wavelengths has allowed the use of LIF technology, in conjunction with CPT technology, to evaluate soil characteristics and hydrocarbon contamination simultaneously. The LIF system has a 0.25-inch sapphire window in the side of the cone that allows a nitrogen laser to scan the soil for fluorescent compounds as the LIF penetrometer rod pushes through soil. The wavelength used in the USACE CPT/LIF system gives the strongest fluorescence signal (attributable to the presence of contamination) for naphthalene and heavier, long-chained hydrocarbons. Thus, while the LIF is not entirely appropriate for detecting the fluorescence of BTEX, it is useful for defining soil contamination because the heavy long-chained hydrocarbons are more likely to sorb to the soil matrix than the more soluble BTEX compounds. Fiber optic cables connected to the laser spectrometer and a 6-pair electrical conductor connected to the CPT data acquisition system are routed through the interior of the push tubes to the CPT probe.

Graphical results of each LIF push are provided in Appendix A. The graphs showed cone resistance, sleeve friction, soil classification, fluorescence intensity, and maximum fluoresced wavelength.

2.2 GEOPROBE® FIELD ACTIVITIES

Geoprobe® field work occurred on May 15 through May 17, 1997. The truck-mounted Geoprobe® system was used to re-install monitoring point MPE, originally installed at an incorrect location using the CPT. The Geoprobe® system is a hydraulically-powered percussion/probing machine used to advance sampling tools through unconsolidated soils. The system relies on static weight from the vehicle combined with percussion as the energy for advancement of the sampling tool. Geoprobe® push rods were manually driven into the ground where the Geoprobe® truck did not have access to install six temporary monitoring points (TMP-1 through TMP-6). TMP-6 did not produce water at a screened depth of 10 feet bgs after two installation attempts and was abandoned.

2.3 GROUNDWATER MONITORING POINT COMPLETION

The term "monitoring point" is used in this report to distinguish these groundwater monitoring stations from conventionally constructed monitoring wells. Completion details for new monitoring points and previously installed monitoring wells are summarized in Table 2.1 and detailed in Appendix A. Figure 2.1 shows the locations of newly completed monitoring points. There are currently 21 groundwater monitoring wells, 3 temporary monitoring wells, and 3 piezometers associated with OU-4. As part of the current investigation, 5 CPT monitoring points and 6 Geoprobe® temporary monitoring points were installed at 11 locations.

2.3.1 Monitoring Point Construction

2.3.1.1 Pre-Installation Activities

All subsurface utility lines and other man-made subsurface features were located, and proposed monitoring point locations were cleared and approved by the Base prior to any drilling activities. Monitoring point locations were adjusted as necessary to avoid damage to subsurface utilities.

2.3.1.2 Equipment Decontamination Procedures

Prior to arriving at the site and between each monitoring point location, all Geoprobe® rods, tips, sleeves, pushrods, samplers, tools, and other downhole equipment were decontaminated using an Alconox® detergent and potable water solution and scrub brush, followed by a potable water rinse.

2.3.1.3 Monitoring Point Materials Decontamination

Monitoring point completion materials were inspected by the field scientist and determined to be clean and acceptable prior to use. All monitoring point completion materials were factory sealed in plastic wrap. Pre-packaged casing, sand, bentonite,

TABLE 2.1
SUMMARY OF WELL INSTALLATION DETAILS
OU-4 RNA TS
SHAW AFB, SOUTH CAROLINA

Well Identification	Installation Date	Northing (feet)	Easting (feet)	Casing Diameter (inches)	TOC Elevation (ft msl)[a/]	Ground Elevation (ft msl)	Total Well Depth (ft bgs)[b/]	Screen Length (feet)
MW-105	3/8/93	782128.419	2166707.029	2.00	214.87	212.92	19.70	5.00
MW-105D	7/13/88	782134.801	2166707.444	2.00	215.11	212.92	176.50	10.00
MW-106	3/10/93	782452.344	2166601.959	2.00	219.21	217.63	24.30	5.00
MW-106D	7/21/88	782448.677	2166595.258	2.00	218.99	217.47	179.50	10.00
MW-107	3/10/93	782281.684	2166296.107	2.00	214.79	213.21	19.90	5.00
MW-111	3/11/93	782234.008	2165610.262	2.00	227.08	225.35	27.60	5.00
MW-112	3/9/93	782153.317	2166456.628	2.00	218.01	215.78	25.00	15.00
MW-112A	2/4/93	782153.806	2166465.881	2.00	217.92	215.78	89.70	10.33
MW-112D	7/24/88	782159.916	2166459.506	2.00	217.73	215.78	155.20	10.00
MW-113	3/10/93	782498.827	2166473.268	2.00	208.95	206.79	25.00	15.00
MW-113A	3/10/93	782490.479	2166472.454	2.00	209.22	207.07	35.00	15.00
MW-114	3/8/93	782369.261	2166797.623	2.00	207.10	204.83	25.00	15.00
MW-115	3/11/93	781886.414	2166877.511	2.00	204.19	201.92	25.00	15.00
MW-115A	2/18/93	781888.874	2166869.608	2.00	204.16	202.19	69.08	10.31
MW-116	2/1/93	781981.943	2166241.078	2.00	219.46	217.20	25.60	15.30
MW-116A	1/21/93	781982.286	2166251.067	2.00	219.48	217.14	94.74	10.33
MW-117	2/5/93	781914.192	2166673.356	2.00	216.42	213.89	21.41	15.24
MW-118	2/15/93	781610.669	2166979.110	2.00	203.51	201.12	10.36	10.31
MW-119A	5/17/94	782159.953	2167543.911	2.00	205.89	203.59	75.30	10.33
TW-101	11/9/86	781707.969	2166693.132	4.00	220.47	218.08	60.00	30.00
TW-120	4/97	782021.000	2167099.000	2.00	194.64	NA[c/]	5.30	NA
TW-121	4/97	781842.000	2167084.000	2.00	198.01	NA	NA	NA
PZ-101	11/8/86	781665.342	2166718.029	2.00	NA	218.53	30.00	10.00
PZ-102	11/11/86	781686.963	2166705.655	2.00	NA	218.53	28.00	10.00
PZ-103	11/11/86	781622.498	2166741.982	2.00	NA	218.63	35.00	10.00
MPA	4/3/97	NA	NA	0.50	NA	NA	18.00	9.84
MPB	4/3/97	NA	NA	0.50	NA	NA	18.00	9.84
MPC	4/3/97	NA	NA	0.50	NA	NA	14.00	9.84
MPD	4/3/97	NA	NA	0.50	NA	NA	23.00	9.84
MPE	5/16/97	NA	NA	SS[d/]	NA	NA	20.00	9.84
TMP-1	5/15/97	NA	NA	SS	NA	NA	8.00	0.50
TMP-2	5/15/97	NA	NA	SS	NA	NA	6.50	0.50
TMP-3	5/15/97	NA	NA	SS	NA	NA	6.50	0.50
TMP-4	5/15/97	NA	NA	SS	NA	NA	8.00	0.50
TMP-5	5/16/97	NA	NA	SS	NA	NA	6.00	0.50
TMP-6	5/16/97	NA	NA	SS	NA	NA	8.00	0.50

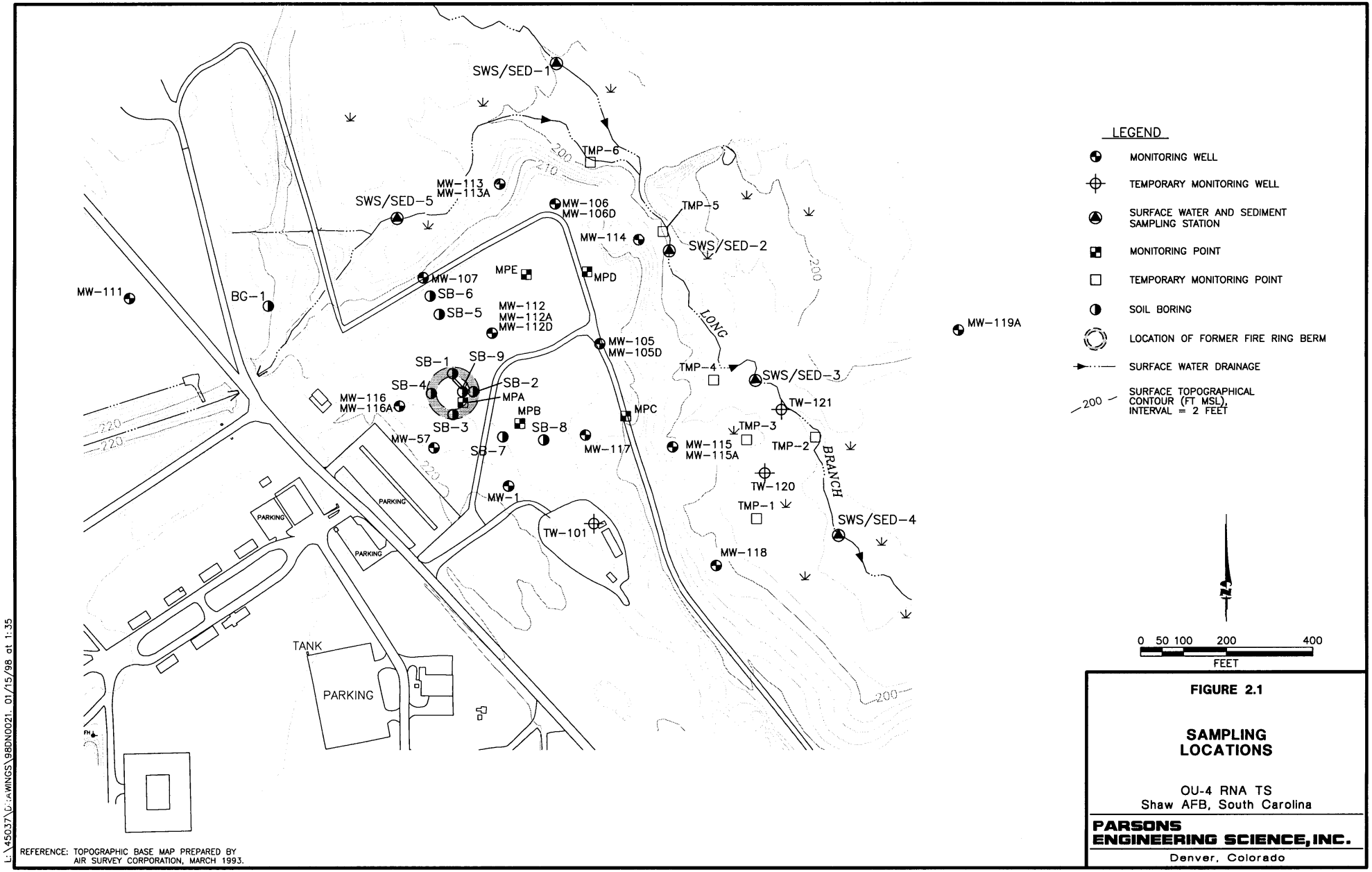
[a/] ft msl = feet above mean sea level.

[b/] ft bgs = feet below ground surface.

[c/] NA = Not available.

[d/] SS = Constructed of 0.25-inch-ID stainless steel screen.

Note: Survey data for monitoring points MPA through MPE were incomplete, therefore indicated as NA.



REFERENCE: TOPOGRAPHIC BASE MAP PREPARED BY AIR SURVEY CORPORATION, MARCH 1993.

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FIGURE 2.1

SAMPLING LOCATIONS

OU-4 RNA TS
Shaw AFB, South Carolina

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and concrete mix were used in point construction, and the bags were inspected for possible external contamination before use. Materials that could not be cleaned to the satisfaction of the field scientist were not used.

2.3.1.4 Monitoring Point Casing and Screen

Two monitoring point designs were used to construct shallow monitoring points. The four monitoring points (MPA through MPD) installed using the CPT were constructed of Schedule 40 polyvinyl chloride (PVC) riser pipe connected to factory-slotted PVC screens having an inside diameter (ID) of 0.5 inch. All PVC casing and screen sections on the shallow monitoring points were flush threaded; glued joints were not used. The riser pipe at each PVC monitoring point was fitted with a PVC top cap, and an aluminum drive point was inserted into the bottom of each PVC screen. The one monitoring point (MPE) installed using the hydraulically-powered Geoprobe® apparatus and the six temporary monitoring points (TMP-1 through TMP-6) driven manually into the ground were constructed with 0.25-inch-ID stainless steel (SS) mesh implants acting as monitoring point screens and 0.25-inch-ID, Teflon®-lined, high-density polyethylene (HDPE) tubing acting as risers connecting the SS mesh to the surface. The SS mesh implants were attached to an aluminum drive points.

Monitoring point screens constructed of PVC were approximately 10 feet long and factory-slotted with 0.010-inch openings. The monitoring points constructed with Teflon®-lined HDPE tubing had screens constructed of 0.5-foot-long SS mesh with pore openings of 0.0057 inch. The bottoms of the SS mesh screens were threaded to dedicated aluminum drive points/implant anchors that remained in place after the drive rods were removed, leaving the riser tubing extended to the surface. The field scientist verified and recorded the borehole depth and the lengths of all casing sections and tubing. All lengths and depths were measured to the nearest 0.1 foot. All monitoring points were screened near the water table.

2.3.2 Monitoring Point Installation

Using the CPT truck, USACE staff installed four 0.5-inch-ID PVC monitoring points MPA, MPB, MPC, and MPD within OU-4 (Figure 2.1). The evacuated hole remaining after extracting the pushrods was cased with PVC riser pipe (introduced through an internal tube running the length of the push rod assembly) as the rods were withdrawn and steam cleaned. These monitoring points were screened at intervals between 4 and 23 feet below ground surface (bgs). Prior to the installation of any CPT monitoring points, soil stratigraphy data were collected with the CPT device from the ground surface to 18 to 50 feet bgs. CPT stratigraphy data are included in Appendix A.

Using the hydraulically powered Geoprobe® apparatus, USEPA staff installed a single 0.2-inch-ID monitoring point at MPE within OU-4 by driving lengths of 1.0-inch-OD probe rod to the desired depth of 20 feet bgs. The downhole end of the drive rod was prefitted with a sacrificial aluminum drive point to decrease soil resistance and to prevent soils from entering the drive rod. After reaching the desired depth, a stainless steel mesh implant was connected to HDPE tubing and threaded through the

center of the Geoprobe® drive rod. The drive rods were then removed with the hydraulically-powered apparatus, leaving the sacrificial tip, screen, and riser tubing in the formation at the desired depth. Formation soils quickly collapsed into the borehole after the removal of the drive rod to create a natural sand pack. Because soils collapsed to the ground surface, no annular sealant (e.g., bentonite) could be placed around the tubing.

Parsons ES staff installed six temporary monitoring points TMP-1 through TMP-6 (Figure 2.1) by manually driving lengths of 1.0-inch-OD probe rod to the desired depth with a 30-pound rod driver. The drive rod was prefitted with a sacrificial aluminum drive point, and HDPE tubing was threaded into this point in the same manner described for MPE. The drive rods were then manually removed, leaving the sacrificial tip, SS screen, and HDPE riser tubing in the formation at the desired depth. The depths to screens ranged from 6 to 8 feet bgs. Formation soils quickly collapsed into the boreholes after the removal of the drive rod to create a natural sand pack. As a result of soils quickly collapsing to the ground surface, no annular sealants (e.g. bentonite) could be placed as a seal around the tubing.

2.3.3 Monitoring Point Development

Prior to sampling, newly installed monitoring points were developed. Typically, well development removes sediment from inside the well casing and flushes fines, cuttings, and drilling fluids from the sand pack and the portion of the formation adjacent to the well screen. Use of the CPT and Geoprobe® to place monitoring points eliminates cuttings and drilling fluids. Therefore, development of these monitoring points was primarily intended to minimize the amount of fine sediment that might accumulate in the casing. Clayey soils in the vicinity of TMP-6 prevented successful monitoring point development after two attempts, and this point was abandoned.

Development was accomplished for monitoring points MPA through MPD using a peristaltic pump with dedicated silicone and HDPE tubing. The pump tubing was regularly lowered to the bottom of the PVC points so that fines were agitated and removed from the point in the development water. For monitoring point MPE and all temporary monitoring points, development was performed by attaching the peristaltic pump tubing directly to the HDPE riser tubing. Typically, development was continued until a minimum of 10 casing volumes of water were removed, and the pH, temperature, and conductivity of the groundwater had stabilized. Development waters were containerized and disposed of at the Base industrial wastewater treatment plant (IWTP). Development records are included in Appendix A.

2.4 GROUNDWATER SAMPLING

This section describes the procedures used for collecting groundwater samples. In order to maintain a high degree of quality control (QC) during this sampling event, the procedures described in the TS work plan (Parsons ES, 1997) and summarized in the following sections were followed. A summary of the chemical analyses performed for groundwater, as well as surface water, sediment, and mobile LNAPL, is presented in Table 2.2.

TABLE 2.2
ANALYTICAL PROTOCOL USED FOR GROUNDWATER, SURFACE WATER, SEDIMENT, AND MOBILE LNAPL SAMPLES
OU-4 RNA TS
SHAW AFB, SOUTH CAROLINA

MATRIX Analyte	METHOD	FIELD (F) OR FIXED-BASE LABORATORY
GROUNDWATER		
Ferrous Iron (Fe^{2+})	Colorimetric, Hach Method 8146	F
ORP	Direct-reading meter	F
Oxygen	Direct-reading meter	F
Dissolved Hydrogen	Reduction Gas Analyzer	F
Hydrogen Sulfide	Colorimetric, Hach Method 8131	
pH	Direct-reading meter	F
Conductivity	Direct-reading meter	F
Temperature	Direct-reading meter	F
Carbon Dioxide	CEHMetrics Method 4500	F
Alkalinity (Carbonate [CO_3^{2-}] and Bicarbonate [HCO_3^-])	F = Titrimetric, Hach Method 8221	F
Nitrate + Nitrite	USEPA Method 353.1	NRMRL[a/]
Chloride	N-601[b/]	NRMRL
Sulfate	N-601	NRMRL
Methane, Ethane, Ethene	RSKSOP-175/RSKSOP-147[c/]	NRMRL
Ammonia-Diss. Gas in Water	E350.1	NRMRL
Total Organic Carbon	RSKSOP-102	NRMRL
Aromatic Hydrocarbons + Fuel Carbon	RSKSOP-122	NRMRL
Chlorinated Volatile Organics	RSKSOP-148	NRMRL
SURFACE WATER		
Aromatic Hydrocarbons + Fuel Carbon	RSKSOP-122	NRMRL
SEDIMENT		
VOCs	USEPA Method 525.2, Revision 3	NRMRL
TOC	RSKSOP-102	NRMRL
MOBILE LNAPL[d/]		
VOCs	USEPA Method 525.2, Revision 3	NRMRL

[a/] USEPA National Risk Management Research Laboratory (NRMRL) in Ada, Oklahoma.
[b/] Waters capillary electrophoresis Method N-601.
[c/] RSKSOP = Robert S. Kerr Laboratory (now NRMRL) Standard Operating Procedure.
[d/] LNAPL = Light nonaquous-phase liquid.

2.4.1 Groundwater Sampling Locations

Groundwater samples were collected from 17 previously installed monitoring wells, and 10 of the 11 newly installed monitoring points. Monitoring point TMP-6 could not be developed, and was abandoned. After completion of installation and development activities, the monitoring points were purged and sampled using a peristaltic pump with dedicated HDPE and silicone tubing for monitoring points MPA through MPD, and by directly attaching the peristaltic pump to the HDPE riser for monitoring point MPE and temporary monitoring points TMP-1 through TMP-5.

2.4.2 Preparation and Equipment Cleaning

All equipment used for sampling was assembled and properly cleaned and calibrated (if required) prior to use in the field. Calibrations were performed in accordance with the manufacturer's specifications. An electrical water level meter was used to measure the static water level in the monitoring well/point prior to initiation of purging. Prior to each use, the water level probe was cleaned with a potable water and phosphate-free, laboratory-grade detergent solution, followed by a distilled-water rinse. In addition, a clean pair of new, disposable latex or nitrile gloves was worn each time a different well or monitoring point was sampled. Dedicated HDPE and silicone tubing were used at each sampling location, eliminating the need for decontaminating these items between wells.

2.4.3 Groundwater Sampling Procedures

2.4.3.1 Preparation of Location

Prior to sampling, the area around the well or monitoring point was cleared of foreign materials, such as brush, rocks, and debris. These procedures prevented sampling equipment from inadvertently contacting debris around the monitoring well/point. The integrity of the monitoring well/point also was inspected, and any irregularities in the visible portions of the well/point, protective cover, or concrete pad were noted.

2.4.3.2 Water Level and Total Depth Measurements

Prior to removing any water from the well or monitoring points, an electrical water level probe or oil/water interface probe was used to measure the depth to groundwater below the well datum to the nearest 0.01 foot. Water levels in the newly installed points constructed of Teflon®-lined HDPE tubing were not obtained because the water level probe diameter was larger than the tubing diameter. If the monitoring well/point depth was not known, the water level probe was then lowered to the bottom of the well/point for measurement of total depth (recorded to the nearest 0.1 foot). Based on these measurements, or using total depths recorded in the RI report (Rust E&I, 1995), the volume of water to be purged from the well/point was calculated. Water level data are reviewed in Section 3.

2.4.3.3 Monitoring Well/Point Purging

Where possible, a minimum of three times the calculated saturated casing volume was removed from each monitoring well/point prior to sampling. Purging continued until the pH, DO concentration, ORP, conductivity, and temperature stabilized between successive readings. Physical and chemical parameters were measured at the well head using field meters and a flow-through cell consisting of an Erlenmeyer flask. A peristaltic pump with dedicated silicone and HDPE tubing was used for well evacuation at all monitoring points and wells TW-120, TW-121, MW-105, MW-111, MW-112, MW-117, and MW-118. For the monitoring points with 0.25-inch HDPE risers, purging was accomplished by attaching the silicone peristaltic pump tubing directly to the top of the monitoring point tubing. For monitoring points with PVC risers and for monitoring wells purged with the peristaltic pump, the HDPE tubing was lowered to within 2 feet of the bottom of the casing. A two-stage submersible pump was used to purge wells MW-107, MW-113, MW-114, MW-115, MW-116, and MW-116A; a one-stage submersible pump was used to purge MW-106; and a Bennett pump was used to purge wells MW-112A and TW-101. In each case, the positive pressure pump was lowered to within 2 feet of the bottom of the casing. The pumps were decontaminated between wells with Alconox® and a distilled-water rinse. TMP-6 did not purge when screened at a depth of 10 feet bgs, and therefore was not sampled. A replacement for TMP-6 was installed at 8 feet bgs, and also did not purge. All purge water was containerized and disposed of at the Base IWTP. Purging and sampling field forms are presented in Appendix A.

2.4.3.4 Sample Collection

A peristaltic pump with dedicated silicone and HDPE tubing was used to extract groundwater samples from the same wells where it was used for purging, along with TW-101, MW-106, MW-112A, and MW-116. In wells containing mobile LNAPL, the pump tubing was lowered through the LNAPL layer to the groundwater under positive air flow to prevent contamination of the inside of the tubing. A two-stage pump was used for sampling wells MW-107, MW-113, MW-114, MW-115, and MW-116A. In almost all cases, the sampling was performed immediately following well purging. For example, at wells where a peristaltic pump was used, the pump was not turned off between purging and sampling activities. In a few instances, the monitoring well/point was purged dry, and the samples were collected after sufficient recharge had occurred. All samples were collected within an hour of purging.

The samples were transferred directly into the appropriate sample containers. The water was carefully poured down the inner walls of each sample bottle to minimize aeration of the sample. Sample bottles for aromatic and chlorinated VOCs and dissolved gases (methane and ethene) were filled so that there was no headspace or air bubbles within the container.

2.4.4 Onsite Chemical Parameter Measurement

DO measurements were taken using a flow-through cell at the outlet of the sampling pump. DO concentrations were recorded after the readings stabilized, and in all cases

represent the lowest DO concentration observed. Because the electrical conductivity, pH, ORP, and temperature of the groundwater can change significantly within a short time following sample acquisition, these parameters also were measured in the field, in the same flow-through cell used for DO measurements. Measured values were recorded on groundwater sampling records (Appendix A). Table 2.2 lists the field methods used to analyze the individual parameters, and analytical results are presented in Section 4.

2.4.5 Sample Handling

The fixed-base analytical laboratory, the National Risk Management Research Laboratory (NRMRL), provided pre-preserved sample containers where appropriate. The sample containers were filled as described in Section 2.4.3.4, and the container lids were tightly closed. The samples were labeled as described in the work plan.

After the samples were sealed and labeled, they were transported to the onsite USEPA mobile laboratory where several analyses were performed. Analytical results are presented in Section 4. USEPA personnel packaged the samples for fixed-base laboratory analysis to prevent breakage and leakage or vaporization from the containers. Sample shipment to NRMRL and the associated chain-of-custody documentation was the responsibility of the USEPA/NRMRL field personnel.

2.5 SURFACE WATER SAMPLING

Surface water samples were collected from five locations along Long Branch Creek and its tributaries in the northeastern portion of OU-4 (Figure 2.1). These samples were collected in order to assess the degree to which VOC-contaminated groundwater was discharging to the surface drainages. The surface water samples were analyzed for both total fuel carbon and CAHs (Table 2.2).

Surface water samples were collected from the west side of Long Branch Creek by placing the sample bottle in the channel with the opening facing up and allowing the water to slowly fill the bottle. Sample handling proceeded as described for groundwater samples in Section 2.4.5. Analytical results are discussed in Section 4.

2.6 SEDIMENT SAMPLING

Stream sediment samples were collected from the same five locations within Long Branch Creek as the surface water samples (Figure 2.1, Table 2.2) following surface water collection. These samples were collected to assess the degree to which VOCs have adsorbed to the bottom of the stream channel. The sediment samples were analyzed for VOCs and TOC (Table 2.2), and results are presented in Section 4.

Sediment samples were collected using a hand auger to excavate 8 inches into the stream bed. The samples were then transferred from the auger to sample containers. Sample handling proceeded as described for groundwater samples in Section 2.4.5.

2.7 LNAPL SAMPLING

Mobile LNAPL samples were collected to assess the chemical composition of on-site source contamination. Free product was encountered at temporary monitoring points MPB and MPC, and sampled using a peristaltic pump. Product samples were collected after groundwater sampling, as the LNAPL level fell during groundwater extraction. If recharge from the aquifer maintained the level of the LNAPL, the product was sampled by slightly raising the extraction tubing.

Mobile LNAPL samples were pumped directly into sample containers. Sample handling proceeded as described for groundwater samples in Section 2.4.5. The analytical method for mobile LNAPL samples is listed in Table 2.2, and results are discussed in Section 4.

2.8 AQUIFER TESTING

During the RI, Rust E&I (1995) performed a pump test at TW-101, and transmissivities were calculated using both the Theis type curve and semilog methods of analysis at TW-101, PZ-101, PZ-102, PZ-103, MW-115, and MW-117. For comparison, slug tests were performed at wells MW-106 and MW-112 to provide estimates for hydraulic conductivity of the shallow aquifer. Slug tests are single-well hydraulic tests used to estimate the hydraulic conductivity of an aquifer in the immediate vicinity of the tested well. Slug testing can be performed using either a rising head or a falling head test. Both rising head and falling head tests were used at this site. Detailed slug testing procedures are presented in the *Technical Protocol for Implementing Intrinsic Remediation with Long-Term Monitoring for Natural Attenuation of Fuel Contamination Dissolved in Groundwater* (Wiedemeier *et al.*, 1995), hereafter referred to as the Technical Protocol document.

Slug tests were performed using a Hermit® data logger and a slug of PVC pipe capped at each end. Data obtained during slug testing were analyzed using the computer program AQTESOLV® (Geraghty & Miller, Inc., 1994) and the methods of Bouwer and Rice (1976) and Bouwer (1989) for unconfined conditions. The results of slug testing are presented in Section 3.3.2.2 and Appendix A.

SECTION 3

PHYSICAL CHARACTERISTICS OF THE STUDY AREA

This section describes the physical characteristics of OU-4 as determined from data collected by Parsons ES in April and May 1997, in conjunction with pertinent data documented in previous site reports (see Section 1.5).

3.1 TOPOGRAPHY, SURFACE HYDROLOGY, AND CLIMATE

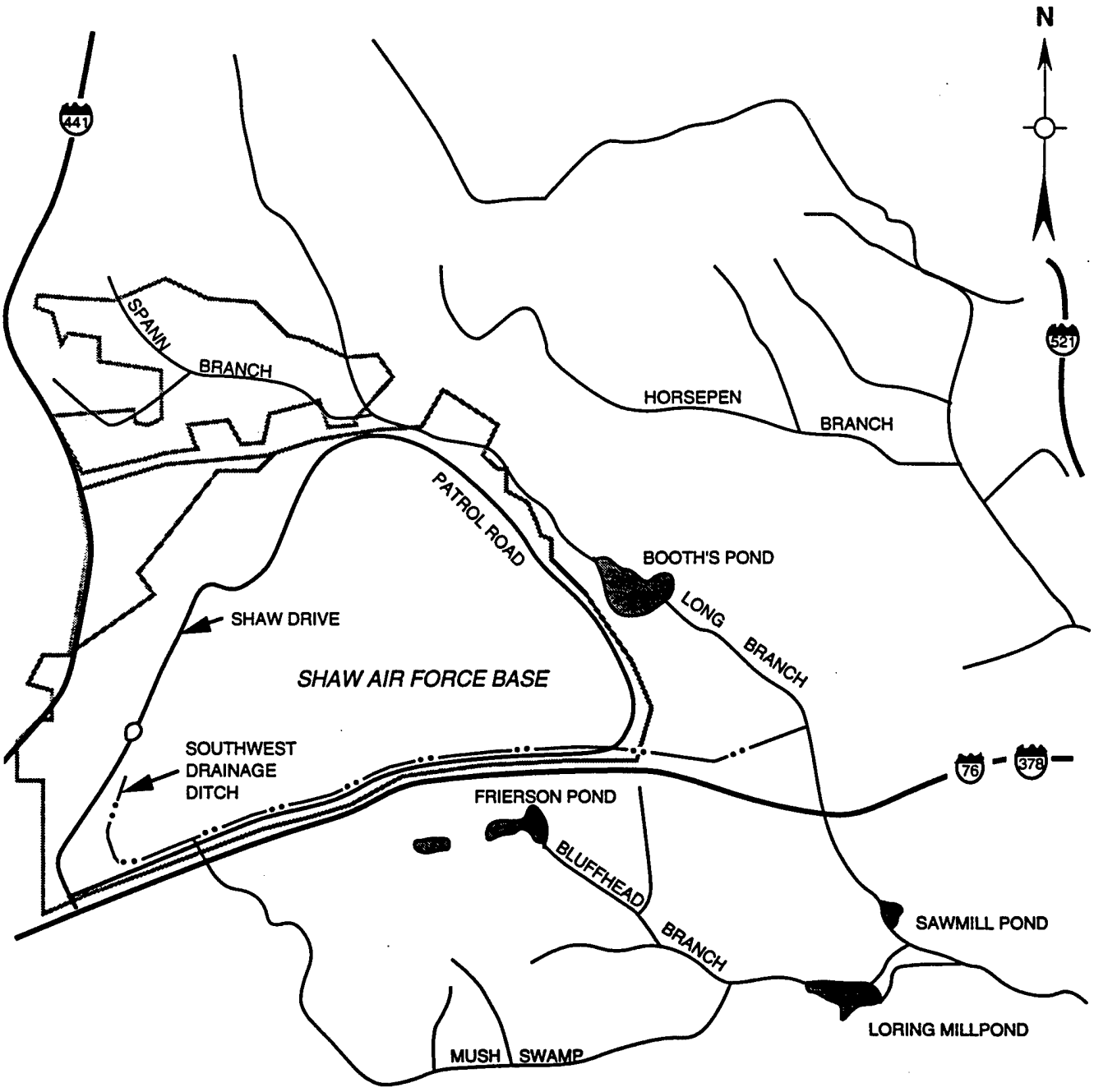
Shaw AFB lies along the border of the Upper and Middle Coastal Plain subprovinces of the Atlantic Coastal Plain Physiographic Province. This transitional boundary is marked by the Orangeburg scarp and expressed at the surface by a change in elevation (Rust E&I, 1995).

Surface water and drainage features in the vicinity of the Base are shown on Figure 3.1. The small perennial stream, Long Branch Creek, and an unnamed southwest drainage ditch both border the Base on the east and south, respectively. The east-flowing drainage ditch joins the south-flowing Long Branch Creek southeast of the Base, approximately 1 mile downstream from Booth's Pond. Several other ponds, including Sawmill Pond, Frierson Pond, and Loring Mill Pond, also are located southeast of the Base (Figure 3.1).

Topography surrounding OU-4 can be characterized as relatively flat in the vicinity of the former bermed fire pit to steeply sloping near Long Branch Creek. Long Branch Creek and an ephemeral tributary that enters Long Branch Creek from the west occupy the Long Branch Creek flood plain and mark the eastern and northern site boundaries, respectively. Elevations range from approximately 198 feet above mean sea level (msl) at Long Branch Creek to approximately 216 feet msl at the bermed former burn pit. Surface runoff drains to the north and east into the bordering streams (Rust E&I, 1995).

In the vicinity of OU-4, Long Branch Creek is 8 to 10 feet wide, 2 to 4 feet deep, and flows at an estimated rate of 1,000 gallons per minute. Long Branch Creek is impounded to form Booth's Pond approximately 2,000 feet downstream from the site. When flowing, the ephemeral stream along the northern boundary of OU-4 can have a width of approximately 4 feet and a depth of 9 inches.

The mean annual temperature at Shaw AFB is 64 degrees Fahrenheit (°F), with an average of 46 °F in January and 81 °F in July. Precipitation averages approximately 46 inches per year distributed relatively evenly throughout the year, with the highest monthly maximum in July and the lowest in October. Average relative humidity is



LEGEND

BASE BOUNDARY

SCALE

0 3,000 6,000

FEET

Source: RUST E&I, 1993.

FIGURE 3.1

SURFACE WATER DRAINAGE

OU-4 RNA TS
Shaw AFB, South Carolina

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relatively constant throughout the year, ranging from 72 to 86 percent (Rust E&I, 1995).

3.2 REGIONAL GEOLOGY AND HYDROGEOLOGY

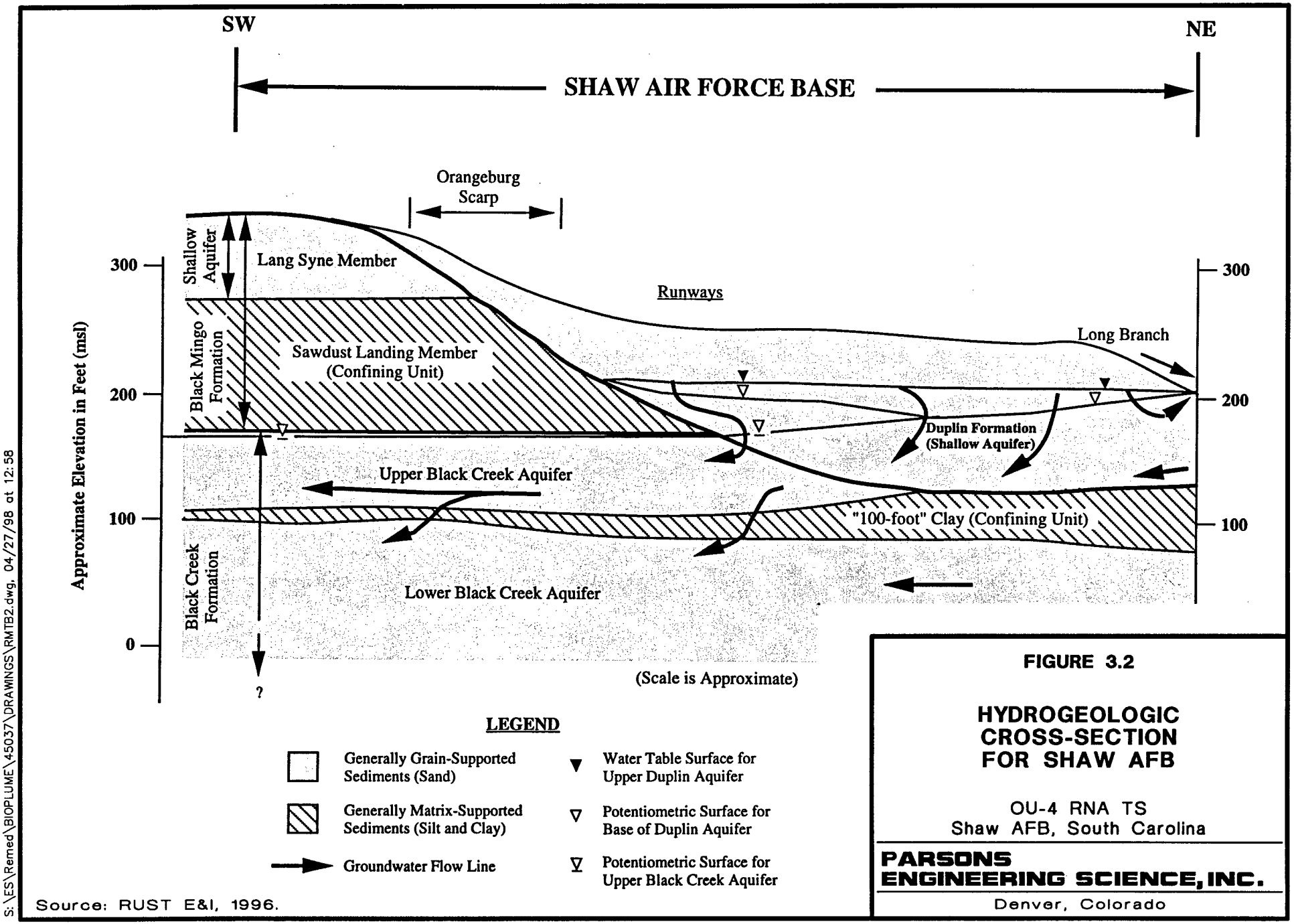
Shaw AFB is underlain by Cretaceous to Quaternary sediments and sedimentary rocks that in turn overlie a basement of Paleozoic crystalline and Triassic sedimentary rocks. These sediments and sedimentary rocks are present as a sedimentary wedge that thickens and dips to the south and southeast. The sedimentary rock sequence at Shaw AFB is approximately 600 to 700 feet thick. Cretaceous formations in this area make up the greatest thickness of sediments and are overlain by 100 to 200 feet of Tertiary and Quaternary sediments. The sedimentary geologic units at the Base, described in ascending order (decreasing age) are the Middendorf Formation, the Black Creek Formation, the Black Mingo Formation, and the Duplin Formation (Figure 3.2).

The Cretaceous Black Creek Formation is the deepest formation encountered to date during environmental investigations at OU-4 (Figure 3.2). The lithology of the Black Creek Formation is predominantly fine- to medium-grained, interbedded, white and gray sands with thin sandstone beds and gray, black, and dark-blue clays. The sediments contain fossils, including shells, sharks teeth, and microfauna. Intervals may contain pyrite, pyrite-coated wood fragments, and marcasite, and may be phosphatic, glauconitic, and micaceous, with interbedded, finely laminated organic clays.

The Paleocene-age Black Mingo Formation (Figure 3.2) outcrops west of the runway at Shaw AFB, and is composed of glauconitic quartz sands, thin layers of gray to light-green silty clay, pyritic dark-gray organic clays, and Fuller's earth (opaline claystone). The Black Mingo Formation locally includes two members: the Sawdust Landing Member and the Lang Syne Member. The Sawdust Landing Member consists of sands, silts, and clays representing upper delta plain deposits, similar to the modern Mississippi River Delta. In the Sawdust Landing Member, significant clay and silt content represents flood-stage deposits, while fine to coarse sands represent channel deposits. As the Paleocene sea transgressed the land, it laid down the cleaner Lang Syne sands and clays. The Lang Syne represents the beach barrier island and back-barrier depositional environments at the seaward margin of the Sawdust Landing delta.

At Shaw AFB, the Duplin Formation unconformably overlies the Black Mingo and Black Creek Formations, and outcrops throughout the eastern two-thirds of the Base. The Orangeburg Scarp is expressed at the ground surface where the Pliocene-age Duplin Formation contacts the eroded surface of the underlying deposits. Locally, this scarp is expressed as the hill traversing the western edge of the Base along Highway 441 (Figure 1.2). The Duplin Formation consists largely of sands, silts, and clays that were derived from the underlying formations and reworked during a sea-level decrease.

Shaw AFB is underlain by three aquifer systems: the Middendorf Aquifer System, the Black Creek Aquifer System, and the Shallow Aquifer System. Aquifer system boundaries do not necessarily correspond to boundaries between geologic formations. In addition, lithologies may change significantly from one area to another within these aquifer systems. The Black Creek and Shallow Aquifer Systems are described below



Source: RUST E&I, 1996.

FIGURE 3.2

HYDROGEOLOGIC CROSS-SECTION FOR SHAW AFB

OU-4 RNA TS
Shaw AFB, South Carolina

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because they are used for the Base water supply and their quality has been adversely impacted by Base activities. A schematic representation of the local aquifers is presented in Figure 3.2, which demonstrates the conceptual relationships among the various geologic formations, aquifer systems, and the Orangeburg Scarp.

The Black Creek Aquifer System underlies most of Sumter County and is used for water supply over most of the central Coastal Plain, including for most of the Base supply. In the vicinity of Shaw AFB, the Black Creek Aquifer is present between approximately 175 feet above msl and 25 feet below msl, and is separated into a lower and upper aquifer by a clay aquitard referred to as the 100-foot clay (Figure 3.2).

In the western portion of the Base, the Shallow Aquifer System is present in sediments associated with the Black Mingo Formation; however, in the vicinity of OU-4, the aquifer is present in the Duplin Formation. The Shallow Aquifer extends from the water table (commonly at 210 to 240 feet above msl) to approximately 150 to 175 feet above msl.

3.3 SITE GEOLOGY AND HYDROGEOLOGY

Two cross-sections modified from the final RI (Rust E&I, 1995) with geologic data collected during the TS field activities, are shown on Figures 3.3 and 3.4. Both cross-sections are roughly parallel to groundwater flow and contaminant migration paths to the northeast and east-southeast.

3.3.1 Lithology and Stratigraphic Relationships

OU-4 lies approximately 1 mile east of the surface expression of the Orangeburg Scarp; therefore, site geology consists of Duplin Formation terrace deposits directly underlain by the Black Creek Formation. The Duplin Formation extends from the surface to a depth of about 80 to 90 feet bgs. Overall, the Duplin Formation at OU-4 consists of unconsolidated, well to poorly graded sands, with approximately 15 percent interstitial clays and silts. Soils in the upper part of this unit are mostly coarse- to fine-grained sands; however, a thin, discontinuous clayey unit was observed in the shallow subsurface in a number of site borings. The lower part of the Duplin Formation consists mostly of medium to fine sands, with clay content increasing with depth. Clay is present both interstitially and in seams. The transition between the lower and upper portions of this unit is gradational.

At OU-4, upper portions of the Black Creek Formation were eroded prior to the deposition of the Duplin Formation terrace deposits, so that the first encountered unit is a clay referred to as the "100-foot clay." This clay unit aquitard was encountered at 90 to 110 feet bgs in three OU-4 boreholes (MW-106D, MW-112D, MW-115D), and is about 20 to 35 feet thick. The unit consists of very stiff, light-gray and very pale brown, plastic clay with seams of poorly graded sands, sandy clays, and silts. The continuity of the silt seams is uncertain. Previous OU-4 investigations indicate that site contamination has not penetrated this clay unit; therefore, the reader is referred to the final RI report (Rust E&I, 1995) for descriptions of the deeper site geology.

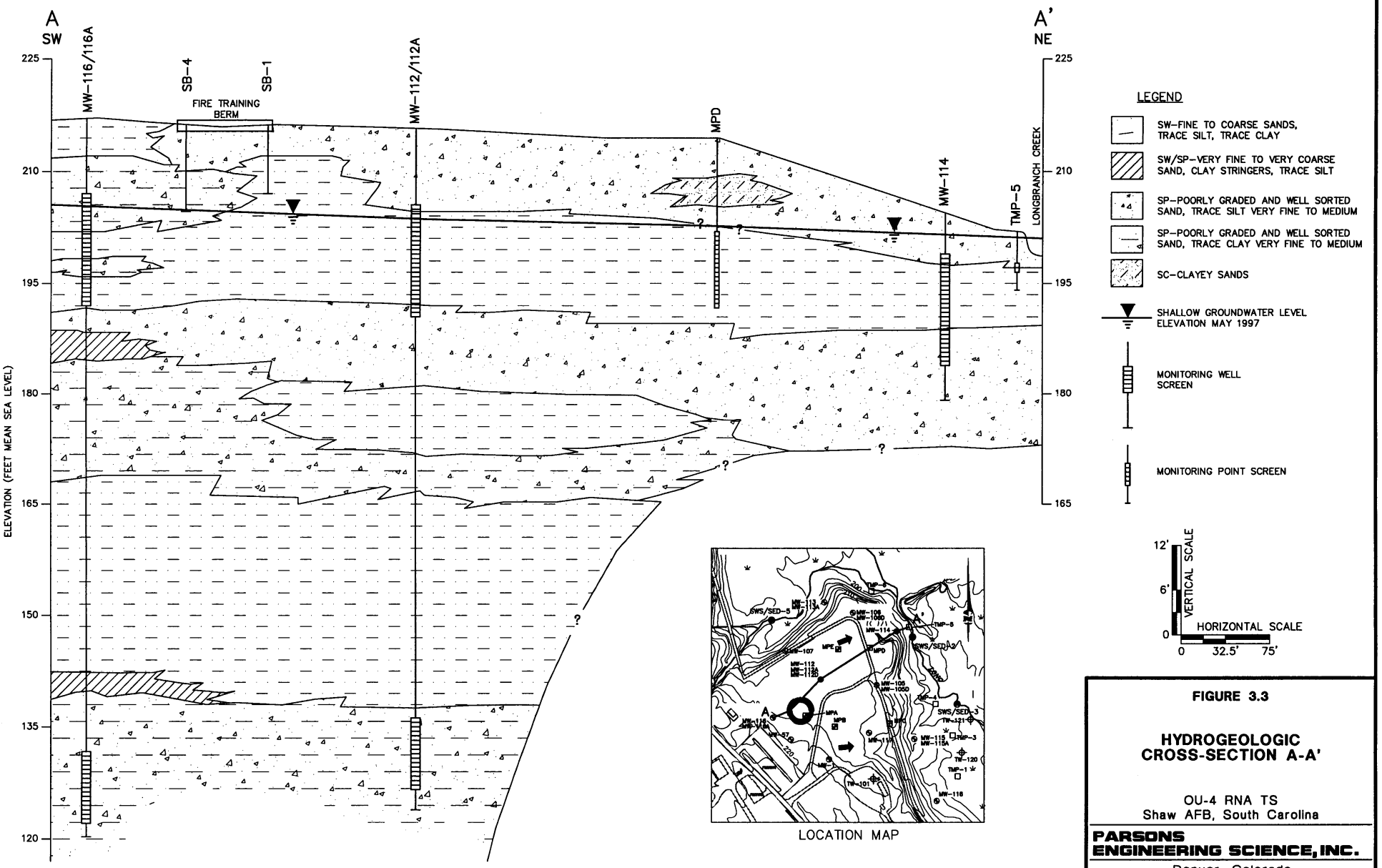

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FIGURE 3.3

HYDROGEOLOGIC CROSS-SECTION A-A'

OU-4 RNA TS
Shaw AFB, South Carolina

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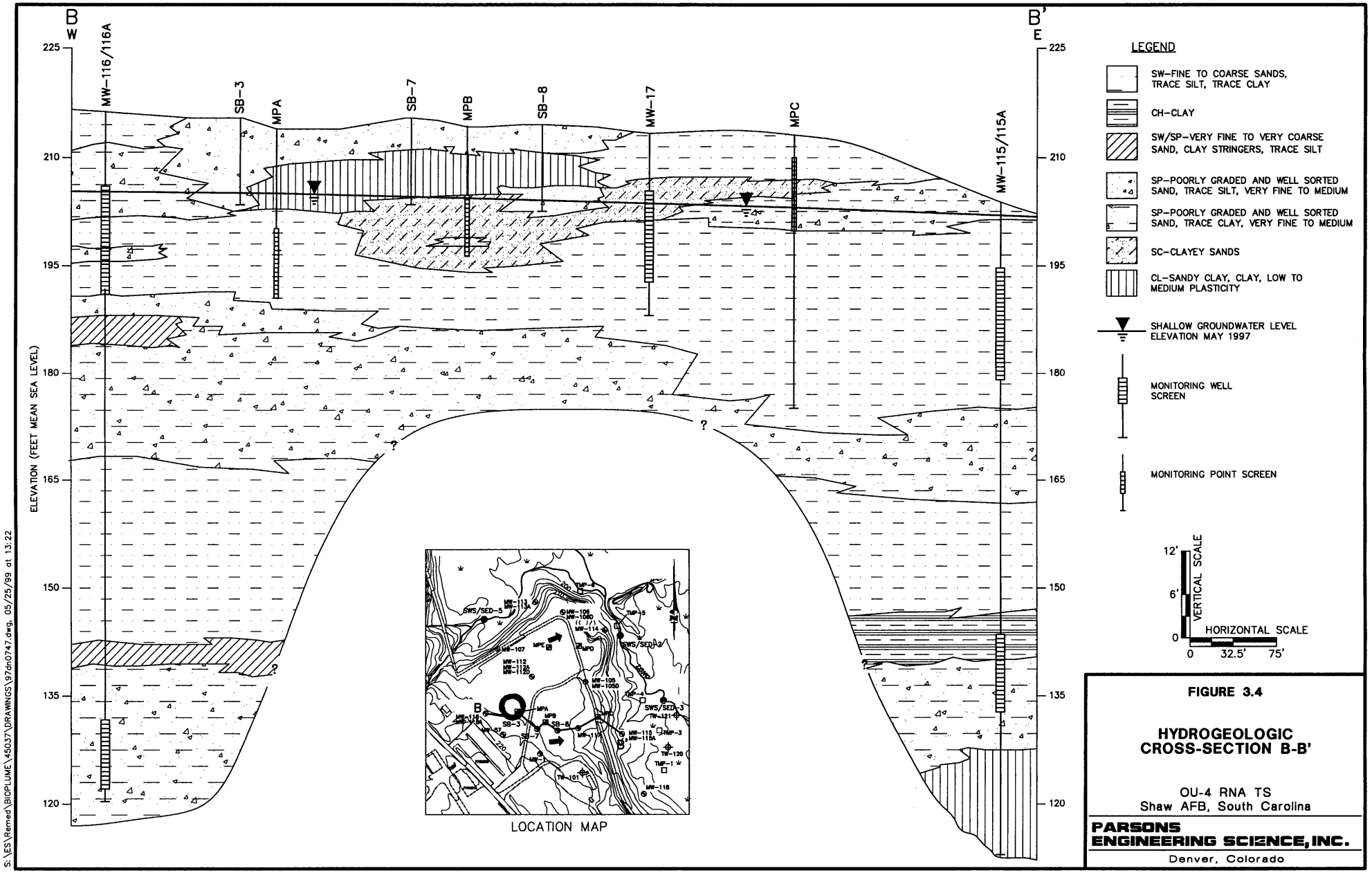

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FIGURE 3.4

HYDROGEOLOGIC CROSS-SECTION B-B'

OU-4 RNA TS
Shaw AFB, South Carolina

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

The water-bearing zone of primary interest at the site is the Shallow Aquifer. At OU-4, this aquifer coincides with the Duplin Formation terrace deposits. The upper portion of the aquifer is characterized by mostly medium to very coarse sands with gravelly layers, all containing interstitial fine sands and clays. With increasing depth, sediments gradually become finer. At a depth of approximately 90 feet bgs, the "100-foot clay" of the Black Creek Formation acts as an aquitard between the shallow aquifer and the underlying Lower Black Creek Aquifer. This is indicated by large head differences between the shallow aquifer and Lower Black Creek Aquifer.

A localized unit consisting of low-permeability, clayey sand is present in the area of the former fire pit at depths ranging from 3 to 9 feet bgs. This low-permeability unit results in both a local groundwater perching effect after heavy rain and a local confining effect on the underlying groundwater. With the exception of this clayey unit, the Shallow Aquifer is unconfined. As the clayey unit was not observed in all borings, its continuity and areal extent have not been fully delineated. Its occurrence at varying depths suggests that the layer may not be continuous.

3.3.2 Groundwater Hydraulics

In the Shallow Aquifer, depth to groundwater ranges from approximately 20 feet bgs beneath the upland terrace to a few inches bgs near Long Branch Creek. May 1997 groundwater elevations are shown in Table 3.1.

3.3.2.1 Flow Direction and Gradient

The shallow aquifer is markedly influenced by surface topography. This is reflected by relatively shallow gradients within the upland terrace portion of the site, and steeper gradients parallel to and underlying the embankments along the flood plain of Long Branch Creek and the unnamed ephemeral stream. As shown on Figure 3.5, groundwater generally flows toward the east/northeast in the shallow aquifer at OU-4. Horizontal groundwater gradients computed from May 1997 data average approximately 0.0048 foot/foot (ft/ft) in the upland terrace portion of the site near the former fire training pit. The groundwater gradient increases to approximately 0.011 ft/ft on the terrace slope and near the creek. The average groundwater gradient from the former fire training pit to the Long Branch Creek is 0.007 ft/ft.

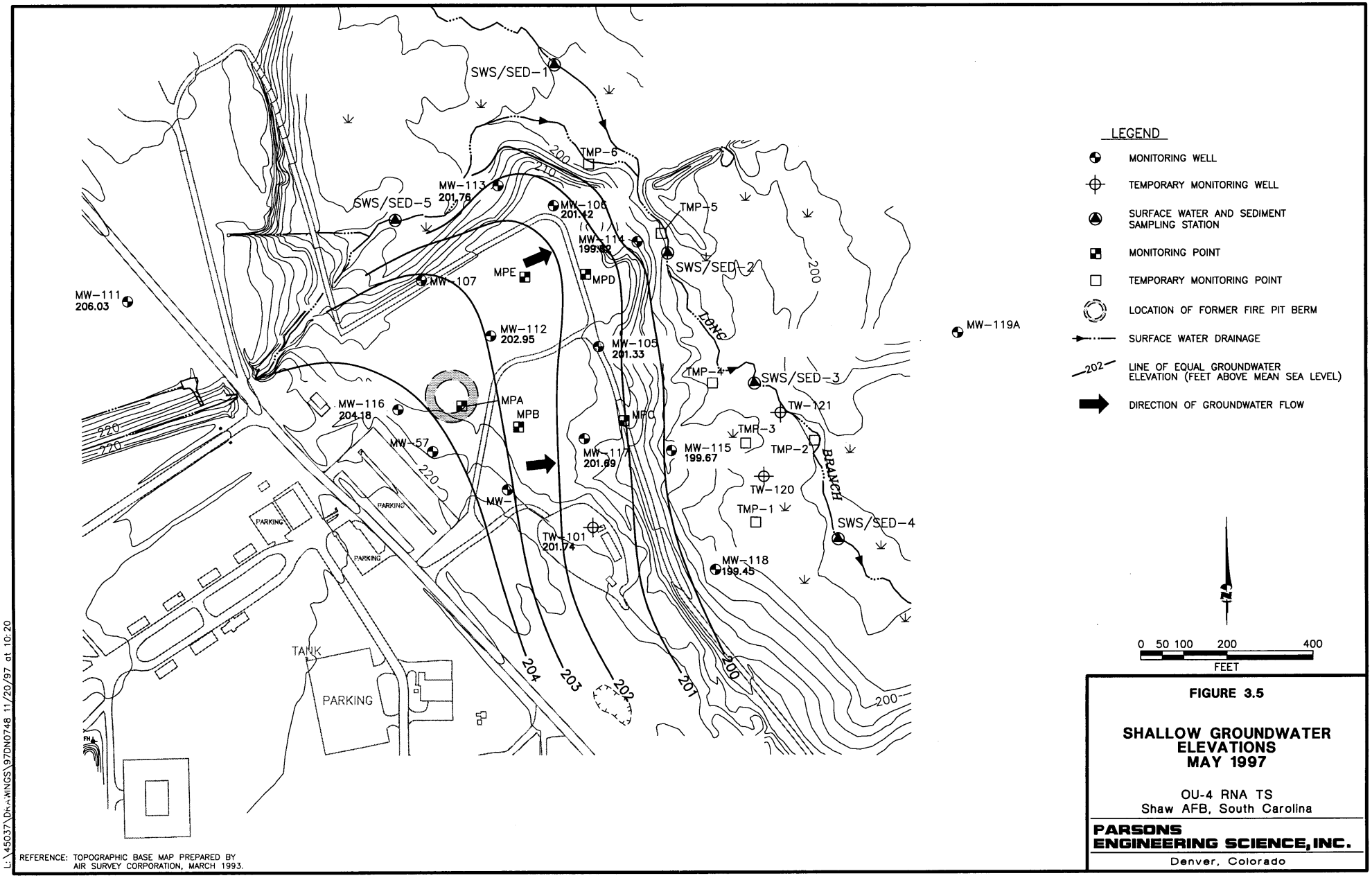
Long Branch Creek receives groundwater from OU-4 through natural gravitational migration of groundwater down the upland terrace and along the embankments of the creek. The creek becomes a hydraulic sink for groundwater (and groundwater contaminants) and acts as a downgradient hydraulic boundary for groundwater migration. This observation is supported by Strack (1989) who provides an example in which a stream penetrates one-tenth of the aquifer thickness and captures approximately 94 percent of the groundwater flow from its ugradient side. The creek depth penetrates as much as five feet into the aquifer in the vicinity of OU-4, where contaminants are primarily limited to the upper 30 feet of shallow aquifer (Section 4). Therefore, the majority of groundwater/dissolved contamination reaching the creek probably will discharge into it with a small fraction hydraulically capable of migration past the creek.

TABLE 3.1
SUMMARY OF GROUNDWATER ELEVATION DATA
MAY 1997
OU-4 RNA TS
SHAW AFB, SOUTH CAROLINA

Well Identification	Elevation of Reference Point for Measurements (feet msl)[a/]	Depth to Groundwater (feet btc)[b/]	Groundwater Elevation (feet msl)
MW-105	214.87	13.54	201.33
MW-106	219.21	17.79	201.42
MW-107	214.79	11.43	203.36
MW-111	227.08	21.05	206.03
MW-112	218.01	15.06	202.95
MW-112A	217.92	19.71	198.21
MW-113	208.95	7.19	201.76
MW-113A	209.22	7.46	201.76
MW-114	207.10	7.28	199.82
MW-115	204.19	4.52	199.67
MW-115A	204.16	7.18	196.98
MW-116	219.46	15.28	204.18
MW-116A	219.48	21.06	198.42
MW-117	216.42	14.73	201.69
MW-118	203.51	4.06	199.45
TW-101	220.47	18.73	201.74

[a/] Feet msl = feet above mean sea level.

[b/] Feet btc = feet below top of casing.



LEGEND

- MONITORING WELL
- TEMPORARY MONITORING WELL
- SURFACE WATER AND SEDIMENT SAMPLING STATION
- MONITORING POINT
- TEMPORARY MONITORING POINT
- LOCATION OF FORMER FIRE PIT BERM
- SURFACE WATER DRAINAGE
- LINE OF EQUAL GROUNDWATER ELEVATION (FEET ABOVE MEAN SEA LEVEL)
- DIRECTION OF GROUNDWATER FLOW

N

0 50 100 200 400
FEET

REFERENCE: TOPOGRAPHIC BASE MAP PREPARED BY AIR SURVEY CORPORATION, MARCH 1993.

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FIGURE 3.5

SHALLOW GROUNDWATER ELEVATIONS MAY 1997

OU-4 RNA TS
Shaw AFB, South Carolina

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

The horizontal gradients measured in May 1997 are consistent with the horizontal gradients measured in March 1993 that ranged from 0.006 ft/ft to 0.033 ft/ft. However, observed heads from March 1993 generally were 2 feet higher. On the basis of groundwater elevations from four wells screened nearer the bottom of the shallow aquifer, the lower zone of the Shallow Aquifer has a horizontal groundwater gradient of 0.003 ft/ft to the southeast.

In addition to differences in flow direction, static water level measurements indicate that there are head differences between the upper and lower zones of the Shallow Aquifer. Downward vertical hydraulic gradients between the upper and lower zones were 0.077 ft/ft at well cluster MW-116, 0.071 ft/ft at well cluster MW-112, and 0.050 ft/ft at well cluster MW-115.

3.3.2.2 Hydraulic Conductivity

As a part of supplemental RI field activities, Rust E&I (1995) performed a 26-minute pump test at well TW-101, which is screened from 30 to 60 feet bgs and is located approximately 400 feet southeast of the fire training pit (Figure 2.1), transverse to the direction of contaminant migration. The average hydraulic conductivity measured at this location was 17.6 feet per day (ft/day) (Rust E&I, 1995). In May 1997, Parsons ES conducted falling- and rising-head slug tests at wells MW-106 and MW-112 and analyzed the test data using the method of Bouwer and Rice (1976) (see Section 2.8). These slug tests yielded hydraulic conductivities of 81 ft/day and 68 ft/day (average of 75 ft/day) measured at wells MW-106 (screened from 14.9 to 19.9 feet bgs and MW-112 (screened from 10 to 25 feet bgs), respectively. These wells are located along the northeastern contaminant migration flow path. The range of hydraulic conductivities measured from the pump test and slug tests (18 to 81 ft/day) are indicative of silty to clean sands.

3.3.2.3 Effective Porosity

Because of the difficulty involved in accurately determining effective porosity, published literature values for soil types comprising the shallow saturated zone were referenced (Spitz and Moreno, 1996). Estimates of effective porosity for fine to medium sand range from 0.08 to 0.30. An average effective porosity of 0.25 was assumed for the Shallow Aquifer at OU-4 considering the predominance of medium-grained sands in the upper saturated zone of the aquifer.

3.3.2.4 Advective Groundwater Velocity

The advective velocity of groundwater in the direction parallel to groundwater flow is given by:

$$\bar{v} = \frac{K}{n_e}\frac{dH}{dL}$$

Where: $\bar{v}$ = Average advective groundwater velocity [L/T]
K = Average slug-test hydraulic conductivity [L/T] (75 ft/day)
dH/dL = Average gradient [L/L] (0.007 ft/ft)
n_e = Effective porosity (0.25).

Using this relationship in conjunction with site-specific data, the average advective groundwater velocity at site OU-4 in May 1997 was 2.1 ft/day, or approximately 770 feet per year (ft/yr).

3.4 GROUNDWATER USE

Potential receptor exposure to groundwater contamination could result through use of water obtained from on-Base supply wells screened within the surficial and Black Creek aquifers. The closest supply well (Base Well 8) is screened within the Shallow Aquifer approximately 700 feet upgradient from the site near the Munitions Flight Unit parking area. There are no other supply wells screened within the Shallow Aquifer in the vicinity of OU-4. The closest supply well screened in the Black Creek Formation is Base Well 10, located approximately 2,000 feet southwest of (upgradient from) OU-4 (Rust E&I, 1996). Base Well 10 reportedly has been abandoned (Rust E&I, 1995). The absence of producing groundwater wells in the vicinity of OU-4 reduces the possibility of a groundwater exposure pathway to potable sources. Off-Base migration of dissolved contaminants to the east/northeast is not expected, because shallow groundwater migrating through OU-4 discharges to Long Branch Creek.

SECTION 4

CONTAMINANT DISTRIBUTION AND EVIDENCE FOR BIODEGRADATION

Soil and groundwater have been contaminated as a result of fire training activities at OU-4. Work performed as part of the RFA (Law, 1989), the RI/FS (Law, 1991; SEC Donohue, Inc., 1992), and supplemental RI work (Rust E&I, 1994) for OU-4 focused on defining the nature and extent of contamination. Data collected during those efforts were supplemented with data collected during natural attenuation sampling in May 1997 and are presented in the following subsections. In particular, this section focuses on data useful for evaluating and modeling the natural attenuation of fuel and chlorinated hydrocarbons dissolved in groundwater.

4.1 CONTAMINANT SOURCES AND SOIL QUALITY

4.1.1 Mobile LANPL Contamination

During fire training exercises between 1941 and 1969, numerous contaminants were burned during fire training exercises, including jet fuel, waste oil, hydraulic fluid, spent solvents, contaminated fuel, and napalm. It is believed that some of the metal drums used to store and transport the combustibles may have been buried at the site, subsequently contributing to soil and groundwater contamination (Rust E&I, 1995). Mobile LNAPL (i.e., free-phase product) was not detected during the previous RFA, RI/FS, or RI investigations; however, mobile LNAPL was observed at monitoring points MPB, MPC, and MPD in May 1997. Groundwater from MPD exhibited only a sheen, while thicker product layers were encountered at MPB and MPC. Mobile LNAPL samples were collected from MPB and MPC for laboratory analysis. The LNAPL at monitoring point MPB was brown in color, highly aromatic, and had a viscosity similar to gasoline when shaken. The LNAPL observed at monitoring point MPC was dark, less aromatic than the LNAPL measured at MPB, and appeared to be more viscous than gasoline when shaken. Several inches of LNAPL likely was present at monitoring points MPB and MPC, though the thicknesses of the LNAPL layers could not be measured because the diameters of the monitoring points (0.5-inch ID) were smaller than the diameter of the oil/water interface probe and available bailers.

The analytical results for product samples collected at MPB and MPC are shown in Table 4.1. The LNAPL samples appear to be extremely weathered, especially with regard to benzene. The benzene, toluene, ethylbenzene, and xylenes (BTEX) information in Table 4.1 is insufficient to identify the original fuel type, but the weathered LNAPL samples likely originated from JP-4 or AVGAS releases. The cosolvenation of trichloroethene (TCE) in the MPC LNAPL suggests that this LNAPL source may have resulted from simultaneous burning of fuels and solvents during

TABLE 4.1
MOBILE LNAPL RESULTS
OU-4 RNA TS
SHAW AFB, SOUTH CAROLINA

Compound	Concentration in Fresh JP-4 [a] (mg/L) [c]	Concentration in Product from MPB [b] (mg/L)	Concentration in Product from MPC (mg/L)
Benzene	3,750	ND [d]	26.4
Toluene	9,975	1,422	3,170
Ethylbenzene	2,775	847	1,140
Total Xylenes	17,400	3,662	4,823
TCE	NA [e]	ND	3,350
Total BTEX	33,900	5,931	9,159.4

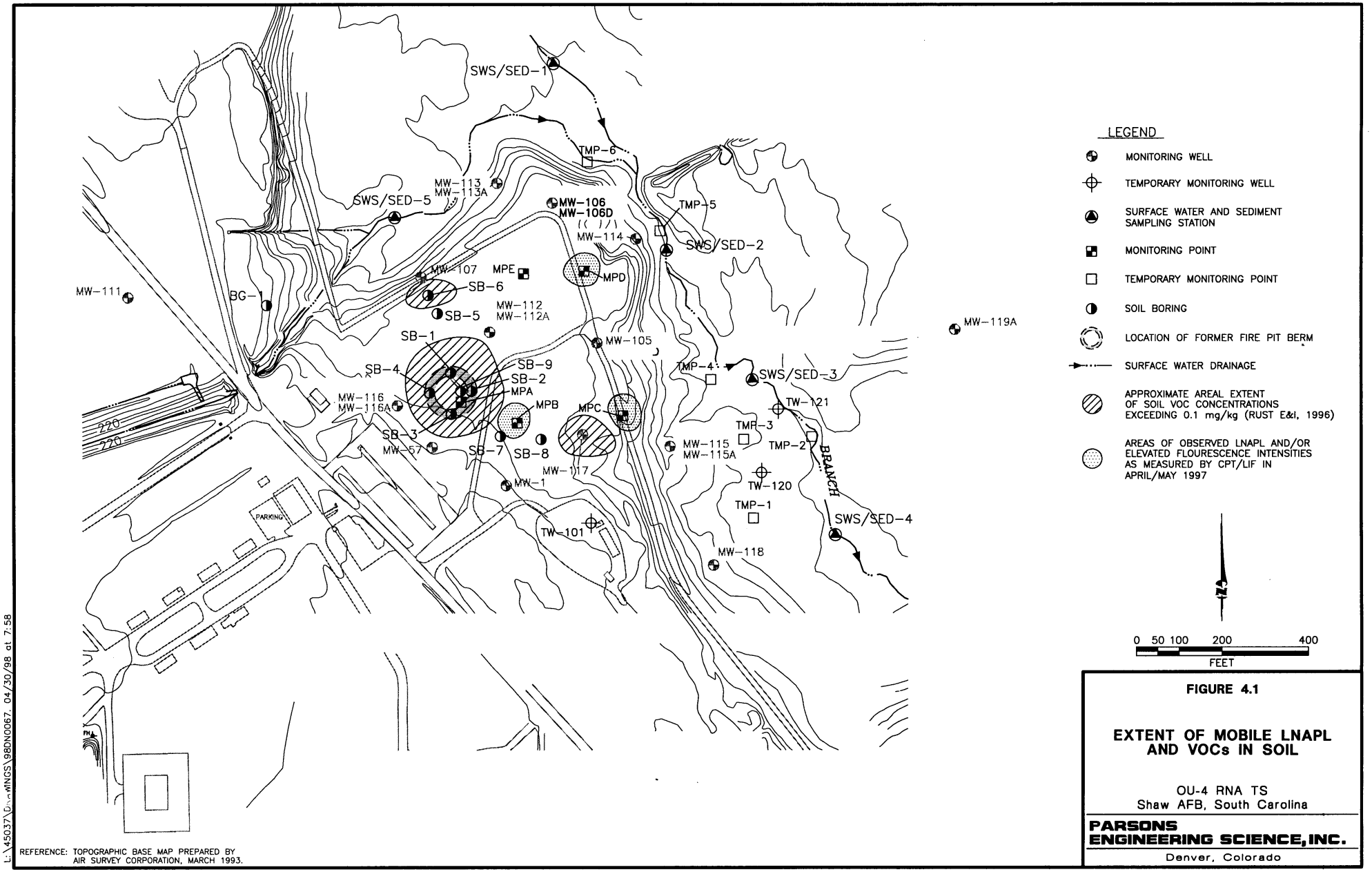
[a] Data from Martel (1987).
[b] USEPA Method 525.2, Revision 3.
[c] mg/L = Milligrams per liter.
[d] ND = Not detected.
[e] NA = Not applicable.

previous fire training operations or leakage from drums previously stored or currently buried at the site.

4.1.2 Soil Contamination

Numerous soil samples were collected during previous site investigations to characterize the extent of soil contamination. Additional soil samples were not collected during this TS; however, LIF data obtained as a part of CPT activities provide additional information on the extent of soil contamination. The areal extent of total VOC contamination in soils as defined during the RI and modified using LIF data is presented on Figure 4.1. A summary of VOC and diesel-range organics analysis results for RI soil samples collected in February/March 1993 is provided in Table 4.2. Detected VOC concentrations consisted primarily of fuel constituents; however, traces of 1,1,1-trichloroethane (TCA), 1,2-dichloroethene (DCE), and tetrachloroethene (PCE) were each measured at four locations.

The highest total VOC concentrations measured during the RI were identified in soil samples collected from a depth of 6 to 8 feet bgs. VOC concentrations exceeding 100 micrograms per kilogram (µg/kg) [0.1 milligrams per kilogram (mg/kg)], centered on three areas that roughly coincided with the three "hot spots" identified from a soil gas survey performed at the site (Law, 1989). The highest total VOC concentrations in soil were detected in the vicinity of the former bermed burn pit at concentrations of up to



REFERENCE: TOPOGRAPHIC BASE MAP PREPARED BY AIR SURVEY CORPORATION, MARCH 1993.

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FIGURE 4.1

EXTENT OF MOBILE LNAPL AND VOCs IN SOIL

OU-4 RNA TS
Shaw AFB, South Carolina

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

TABLE 4.2
SUMMARY OF DETECTED VOLATILE AND DIESEL-RANGE ORGANIC COMPOUNDS IN OU-4 SOIL SAMPLES COLLECTED IN FEBRUARY/MARCH 1993
OU-4 RNA TS
SHAW AFB, SOUTH CAROLINA

Sample ID	1,1,1-TCA (µg/kg)[a/]	PCE (µg/kg)	Total 1,2-DCE (µg/kg)	Ethylbenzene (µg/kg)	Toluene (µg/kg)	Total Xylenes (µg/kg)	Diesel-Range Organics (mg/kg)[b/]
MW-112A-2	< 5.6[c/]	3.3 J[d/]	< 5.6	< 5.6	< 5.6	< 5.6	<3.5
MW-112A-8	< 5.8	< 5.8	< 5.8	< 5.8	< 5.8	< 5.8	<3.8
MW-112A-14	< 5.7	< 5.7	< 5.7	< 5.7	< 5.7	< 5.7	14
MW-115A-3	< 6.8	< 6.8	11	5 J	6.5 J	14	47
MW-116-2	< 5.2	< 5.2	< 5.2	< 5.2	< 5.2	< 5.2	5.4
MW-116-7	< 5.2	< 5.2	< 5.2	< 5.2	< 5.2	< 5.2	4.1
MW-116-12	< 5.7	< 5.7	< 5.7	< 5.7	< 5.7	< 5.7	4.6
MW-116A-2	< 5.2	2.6 J	< 5.2	< 5.2	< 5.2	< 5.2	6.2
MW-116A-8	< 5.5	< 5.5	< 5.5	< 5.5	< 5.5	< 5.5	<3.7
MW-116A-14	< 5.8	< 5.8	< 5.8	< 5.8	< 5.8	< 5.8	<3.8
MW-117-2	< 5.4	< 5.4	< 5.4	< 5.4	< 5.4	< 5.4	13
MW-117-7	< 30	< 30	< 30	100	< 30	640	190
MW-117-12	< 5.9	< 5.9	< 5.9	4.3 J	< 5.9	9.4	5.5
MW-118-2	< 6.3	< 6.3	< 6.3	< 6.3	< 6.3	< 6.3	13
MW-119A-1	< 5.4	< 5.4	< 5.4	< 5.4	< 5.4	< 5.4	3.9
MW-119A-4	< 5.6	< 5.6	< 5.6	< 5.6	< 5.6	< 5.6	2.3J
SB-1-2	< 28	< 28	< 28	150	28	440	7300
SB-1-8	< 570	< 570	< 570	3000	< 570	10000	6300
SB-1-12	< 5500	< 5500	< 5500	17000	23000	75000	5200
SB-2-2	< 5.3	< 5.3	< 5.3	< 5.3	< 5.3	< 5.3	200
SB-2-8	< 570	490 J	< 570	140 J	< 570	630	1200
SB-3-2	< 5.5	< 5.5	< 5.5	< 5.5	< 5.5	< 5.5	20
SB-3-8	< 550	< 550	< 550	150J	< 550	750	3500
SB-3-12	< 56	< 56	< 56	190	< 56	1500	430
SB-4-2	< 530	< 530	< 530	490 J	170 J	3700	9500
SB-4-8	< 14000	< 14000	< 14000	< 14000	< 14000	35000	5700
SB-4-12	< 6000	< 6000	< 6000	10000	13000	91000	2000
SB-5-2	< 27	< 27	< 27	< 27	< 27	< 27	550
SB-5-8	< 5.9	< 5.9	< 5.9	< 5.9	< 5.9	< 5.9	<3.8
SB-5-12	< 5.7	< 5.7	< 5.7	< 5.7	< 5.7	< 5.7	8
SB-6-2	< 5.5	< 5.5	< 5.5	< 5.5	< 5.5	< 5.5	290
SB-6-8	140 J	< 570	< 570	1900	300 J	12000	1100
SB-6-12	< 5600	< 5600	< 5600	4700 J	1300 J	23000	110
SB-7-2	< 5.3	< 5.3	< 5.3	< 5.3	< 5.3	< 5.3	81
SB-7-8	< 5.8	< 5.8	< 5.8	< 5.8	< 5.8	< 5.8	5.4
SB-7-12	< 5600	< 5600	< 5600	< 5600	< 5600	< 5600	650
SB-8-2	< 5.3	< 5.3	< 5.3	< 5.3	< 5.3	< 5.3	5.4
SB-8-8	< 5.8	< 5.8	< 5.8	< 5.8	< 5.8	< 5.8	<3.4
SB-9-2	< 530	< 530	< 530	1300	< 530	3100	3900
SB-9-6	< 560	< 560	< 560	640	< 560	980	3600
SB-9-10	< 570	< 570	< 570	790	< 570	710	3400

[a/]ug/kg = Micrograms per kilogram. Source: Rust E&I, 1995.

[b/]mg/kg = Milligrams per kilogram.

[a/]< = Not detected down to 10% of the quantitation limit listed.

[b/]J = Estimated value less than the quantitation limit.

115,000 µg/kg (115 mg/kg as combined total of ethylbenzenes, toluene, and xylenes). This area also contained the only VOC concentrations detected above 100 µg/kg in soil samples collected from 0 to 3 feet bgs (at SB-4 and SB-9). Nevertheless, the detection of VOCs in two areas beyond the still-recognizable burn pit suggested that secondary contaminant sources are present at the site. These two areas center around MW-117, east of the pit, and SB-6 located north of the pit (Figure 4.1).

Soil and mobile LNAPL contamination detected during this TS expanded the known extent of soil contamination identified during the RI, especially in the vicinity of MW-117. Fluorescent aromatic compounds indicative of hydrocarbon contamination were observed at locations MPA, MPB, and MPC (also coinciding with mobile LNAPL observations at MPB and MPC) during monitoring point installation with the CPT/LIF. As shown on Figure 4.1, mobile LNAPL (Section 4.1.1) and LIF data obtained at monitoring point MPB indicate a possible connection between soil contamination measured in the fire training pit and around MW-117. LNAPL may have migrated away from the training pit toward MW-117; however, mobile LNAPL likely originated from two separate sources, one near the fire training pit (MPB) and the other near a suspected former drum storage or fire training location (MPC). Similarly, mobile LNAPL and LIF data obtained at monitoring point MPC suggests that soil contamination extends farther north/northeast of MW-117 than delineated during the RI.

Although relatively thin zones of fluorescent compounds were identified atop the water table during CPT/LIF activities, it is possible that an LNAPL smear zone exists elsewhere in the vicinity of MW-117 that contributes to mobile LNAPL volumes as groundwater elevations fluctuate. The detection of high fluorescence intensities from 8 to 12 feet bgs at MPC suggests that mobile LNAPL is residing on the water table and acting as the primary contaminant source at MPC [the groundwater depth at MPC is approximately 10 feet bgs (Table 3.1)]. High fluorescence intensities from 6 to 15 feet bgs at monitoring point MPB suggest the possible presence of residual LNAPL contamination (in addition to the mobile LNAPL) at this location and may indicate a zone of smeared contamination above and below the water table. Fluorescence detections from 6 to 10 feet bgs at MPA in the fire training pit are consistent with previous detections of VOCs in soil in this area (Table 4.2), and indicate that significant fuel contamination might still be present. CPT/LIF logs are reproduced in Appendix A.

Soil contamination profiles measured during the RI most likely have been altered through site remediation activities that have occurred over the past 3 years. For example, after 1 year of bioventing in the former bermed burn pit, BTEX concentrations decreased more than 90 percent within approximately 30 feet of the vent wells (Parsons ES, 1996b). The effects of bioventing beyond 30 feet from the vent wells and after an additional 1.5 years of bioventing are not known. Also, hydrogen peroxide injection during November 1996 in the vicinity of MW-117 may have induced changes in soil VOC concentrations in this area. During the pilot test, water levels were temporarily raised to the ground surface, which may have contributed to an increase in the thickness of the residual LNAPL smear zone, resulted in *in situ* soil washing, and/or caused the accelerated migration of mobile LNAPL (LNAPL was observed at MPC, downgradient from MW-117). Soil gas emissions also increased during the test as a result of groundwater sparging; it is unclear if soil gas emissions

affected soil VOC concentrations. Remediation that could have affected soil VOC concentrations in the vicinity of the soil contamination near SB-6 has not been attempted.

The areal extent of DRO concentrations roughly coincides with the extent of VOC contamination (Table 4.2); however, DROs were more widespread than total VOCs in 0- to 3-foot bgs samples. This is a probable result of the site grading reported by Rust E&I (1995). The disturbance from grading likely would volatilize any VOCs in shallow soils while dispersing the DRO over a somewhat larger area. Given that the berm for the former burn pit is still evident, it is likely that this area was not graded; therefore, any VOCs residing in the shallow soils in this area would have remained undisturbed.

4.2 OVERVIEW OF HYDROCARBON BIODEGRADATION

Mechanisms for natural attenuation of chlorinated solvents and BTEX include biodegradation, dispersion, dilution from recharge, sorption, and volatilization. Of these processes, biodegradation is the only mechanism working to transform contaminants into ultimately innocuous byproducts. Intrinsic bioremediation occurs when indigenous microorganisms work to bring about a reduction in the total mass of contamination in the subsurface without the addition of nutrients. In order to provide a foundation for interpreting site data, the following subsections review the major bioremediation processes that act upon CAHs and BTEX. Because the terminology describing biodegradation of both types of compounds is similar, a generalized review of the processes is presented first.

4.2.1 Review of Biodegradation Processes

Microorganisms obtain energy for cell production and maintenance by facilitating thermodynamically advantageous reduction oxidation (redox) reactions involving the transfer of electrons from electron donors to available electron acceptors. This results in the oxidation of the electron donor and the reduction of the electron acceptor. Electron donors may be natural organic carbon, fuel hydrocarbon compounds, and less-chlorinated solvents [e.g., vinyl chloride (VC), DCE, dichloroethane (DCA), or chlorinated benzenes ranging from chlorobenzene (CB) to tetrachlorobenzene (TeCB)]. Fuel hydrocarbons or solvents are completely degraded or detoxified if they are utilized as the primary electron donor (i.e., as a primary substrate or carbon source) for microbial metabolism (Bouwer, 1992). Electron acceptors are elements or compounds that occur in relatively oxidized states, and include oxygen, nitrate, ferric iron, sulfate, manganese, carbon dioxide, and highly chlorinated solvents [e.g., PCE, TCE, tetrachloroethane (PCA), TCA, and polychlorinated benzenes].

The driving force of biodegradation is electron transfer, which is quantified by the Gibbs free energy of the reaction ($\Delta G°_r$) (Stumm and Morgan, 1981; Bouwer, 1994; Godsey, 1994). The value of $\Delta G°_r$ represents the quantity of free energy consumed ($\Delta G°_r > 0$) or yielded ($\Delta G°_r < 0$) to the system during the reaction. Although thermodynamically favorable, most of the reactions involved in biodegradation of fuel hydrocarbons or chlorinated hydrocarbons cannot proceed abiotically because of the lack of activation energy. Microorganisms are capable of providing the necessary activation energy; however, they will facilitate only those redox reactions that have a

net yield of energy (i.e. $\Delta G°_r < 0$). Most reactions involving biodegradation of contaminants do yield energy to the microbes; however, in many cases specific geochemical conditions are necessary for this reaction to be favorable and to allow the appropriate microbial population to develop and grow.

Microorganisms preferentially utilize electron acceptors while metabolizing hydrocarbons (Bouwer, 1992). DO is utilized first as the prime electron acceptor. It is under these conditions (i.e., aerobic conditions) that fuel hydrocarbons and the less chlorinated solvents are most commonly used as electron donors. After the DO is consumed, anaerobic microorganisms use native electron acceptors in the following order of preference: nitrate, manganese, ferric iron hydroxide, sulfate, and finally carbon dioxide. Under anaerobic conditions, BTEX compounds and other fuel hydrocarbons are still used as electron donors. Chlorinated solvents that are susceptible to reductive dehalogenation generally are used as electron acceptors when aquifer conditions are such that sulfate or carbon dioxide is the preferred electron acceptor.

In addition to being controlled by the energy yield of the reaction, the expected sequence of redox processes is also a function of the ORP of the groundwater. This potential is a measure of the relative tendency of a solution or chemical reaction to accept or transfer electrons. As each subsequent electron acceptor is utilized, the groundwater becomes more reducing, and the ORP of the water decreases. The main force driving this change in ORP is microbially mediated redox reactions. ORP can be used as an indicator of which redox reactions may be operating at a site. Environmental conditions and microbial competition ultimately determine which processes will dominate.

Depending on the types and concentrations of electron acceptors present (e.g., nitrate, sulfate, carbon dioxide), pH conditions, and ORP, anaerobic biodegradation can occur by denitrification, manganese reduction, ferric iron reduction, sulfate reduction, or methanogenesis. Other, less common anaerobic degradation mechanisms such as manganese or nitrate reduction may dominate if the physical and chemical conditions in the subsurface favor use of these electron acceptors. Vroblesky and Chapelle (1994) show that the dominant terminal electron accepting process can vary both temporally and spatially in an aquifer with fuel hydrocarbon contamination.

4.2.2 Biodegradation of BTEX

Numerous laboratory and field studies have shown that hydrocarbon-degrading bacteria can participate in the degradation of many of the chemical components of fuel hydrocarbons, including the BTEX compounds (Jamison *et al.*, 1975; Atlas, 1981, 1984, 1988; Gibson and Subramanian, 1984; Reinhard *et al.*, 1984; Young, 1984; Bartha, 1986; Wilson *et al.*, 1986, 1987, and 1990; Barker *et al.*, 1987; Baedecker *et al.*, 1988; Lee, 1988; Chiang *et al.*, 1989; Grbic-Galic, 1989 and 1990; Cozzarelli *et al.*, 1990; Leahy and Colewell, 1990; Altenschmidt and Fuchs, 1991; Alvarez and Vogel, 1991; Baedecker and Cozzarelli, 1991; Ball *et al.*, 1991; Bauman, 1991; Borden, 1991; Brown *et al.*, 1991; Edwards & Grbic-Galic., 1992; Evans *et al.*, 1991a and 1991b; Haag *et al.*, 1991; Hutchins and Wilson, 1991; Hutchins *et al.*, 1991a and 1991b; Beller *et al.*, 1992; Bouwer, 1992; Edwards and Grbic-Galic, 1994; Thierrin *et al.*, 1992; Malone *et al.*, 1993; Davis *et al.*, 1994). Fuel hydrocarbons biodegrade naturally when an indigenous population of hydrocarbon-degrading microorganisms is

present in the aquifer and sufficient concentrations of electron acceptors and nutrients are available to these organisms.

During biodegradation of fuel hydrocarbons, the fuel compounds are used as electron donors. They are the primary substrate ("food") for the microbes, while the electron acceptors provide the oxidant used to reduce (metabolize) the substrate and produce energy. In most subsurface environments, both aerobic and anaerobic degradation of fuel hydrocarbons can occur, often simultaneously in different parts of the plume. The nearly ubiquitous nature of these processes is well documented (e.g., Rice *et al.*, 1995; Wiedemeier *et al.*, 1995; Kuehne and Buscheck, 1996, and Mace *et al.*, 1997). Aerobic destruction of BTEX compounds dissolved in groundwater results in the consumption (reduction) of DO and the formation of carbon dioxide. Anaerobic destruction of the BTEX compounds is associated with the accumulation of fatty acids, production of methane, solubilization of iron, and reduction of nitrate and sulfate (Cozzarelli *et al.*, 1990; Wilson *et al.*, 1990).

4.2.3 Biodegradation of Chlorinated Solvents

Chlorinated solvents can be transformed, directly or indirectly, by biological processes (Bouwer *et al.*, 1981; Miller and Guengerich, 1982; Reineke and Knackmuss, 1984; Wilson and Wilson, 1985; de Bont *et al.*, 1986; Nelson *et al.*, 1986; Spain and Nishino, 1987; Bouwer and Wright, 1988; Little *et al.*, 1988; Mayer *et al.*, 1988; Arciero *et al.*, 1989; Cline and Delfino, 1989; Freedman and Gossett, 1989; Folsom *et al.*, 1990; Harker and Kim, 1990; Alvarez-Cohen and McCarty, 1991a, 1991b; DeStefano *et al.*, 1991; Henry, 1991; Sander *et al.*, 1991; McCarty *et al.*, 1992; Hartmans and de Bont, 1992; Chapelle, 1993; McCarty and Semprini, 1994; Vogel, 1994; Suflita and Townsend, 1995; Bradley and Chapelle, 1996; Klier *et al.*, 1996; Spain, 1996). Biodegradation of CAHs and chlorinated benzenes results from the same general processes that bring about biodegradation of fuel hydrocarbons. However, a more complex series of processes often is involved, and CAHs and chlorinated benzenes may act as either substrates (electron donors) or electron acceptors, depending upon the prevailing geochemical conditions.

Whereas BTEX are biodegraded in essentially one step by acting as an electron donor/carbon source, CAHs and chlorinated benzenes may undergo several types of biodegradation involving several steps. Chlorinated solvents may undergo biodegradation through three different pathways: use as an electron acceptor, use as an electron donor, or cometabolism, which is degradation resulting from exposure to a catalytic enzyme fortuitously produced during an unrelated process. At a given site, one or all of these processes may be operating, although at many sites the use of CAHs as electron acceptors appears to be most likely.

In a pristine aquifer, native organic carbon is utilized as an electron donor and DO is utilized first as the prime electron acceptor. Where anthropogenic carbon (e.g., fuel hydrocarbons, less-chlorinated CAHs, or chlorinated benzenes with four or fewer chlorines) is present, it also may be utilized as an electron donor. Most chlorinated solvents that can act as electron donors have thus far only been demonstrated to do so under aerobic conditions, with the notable exception of VC (Bradley and Chapelle, 1996). After the DO is consumed, anaerobic microorganisms typically use native electron acceptors (as available) in the following order of preference: nitrate, ferric

iron oxyhydroxide, sulfate, and finally carbon dioxide. Evaluation of the distribution of these electron acceptors can provide evidence of where and how biodegradation of chlorinated solvents is occurring. In addition, because solvents may be used as electron acceptors or electron donors (in competition with other acceptors or donors), isopleth maps showing the distribution of these compounds also will provide evidence of the types of biodegradation processes acting at a site. A more complete description of the main types of biodegradation reactions affecting chlorinated solvents dissolved in groundwater is presented in the following subsections.

4.2.3.1 Electron Acceptor Reactions (Reductive Dehalogenation)

Under anaerobic conditions, biodegradation of chlorinated solvents usually proceeds through a process called reductive dehalogenation. During this process, the halogenated hydrocarbon is used as an electron acceptor, not as a source of carbon, and a halogen atom is removed and replaced with a hydrogen atom. As an example, Figure 4.2 illustrates the transformation of chlorinated ethenes via reductive dehalogenation. In general, reductive dehalogenation of chlorinated ethenes occurs by sequential dehalogenation from PCE to TCE to DCE to VC to ethene. An analogous pattern for chlorinated ethanes might be PCA to TCA to DCA to chloroethen, and for chlorinated benzenes the pattern might be TeCB to trichlorobenzene (TCB) to dichlorobenzene (DCB) to CB. Depending upon environmental conditions, these sequences may be interrupted, with other processes (e.g., aerobic or abiotic degradation) then acting upon the products. Reductive dehalogenation of chlorinated solvent compounds is associated with the accumulation of daughter products and an increase in chloride.

Reductive dehalogenation affects chlorinated compounds differently. Of the ethenes, PCE is the most susceptible to reductive dehalogenation because it is the most oxidized. Conversely, VC is the least susceptible to reductive dehalogenation because it is the least oxidized of these compounds. Likewise, hexachlorobenzene is more susceptible to reductive dehalogenation than less-chlorinated benzenes. In general, the rate of reductive dehalogenation of chlorinated solvents has been observed to decrease as the degree of chlorination decreases (Vogel and McCarty, 1985; Bouwer, 1994). Murray and Richardson (1993) have postulated that this rate decrease may explain the accumulation of VC in PCE and TCE plumes that are undergoing reductive dehalogenation.

In addition to being affected by the degree of chlorination of the compound, reductive dehalogenation also can be controlled by the redox conditions of the site groundwater system. In general, reductive dehalogenation has been demonstrated under anaerobic nitrate- and sulfate-reducing conditions, but the most rapid biodegradation rates, affecting the widest range of compounds, occur under methanogenic conditions (Bouwer, 1994). Dehalogenation of PCE and TCE to DCE can proceed under mildly reducing conditions such as nitrate reduction or iron(III) reduction (Vogel *et al.*, 1987), while the transformation of DCE to VC, or the transformation from VC to ethene requires more strongly reducing conditions (Freedman and Gossett, 1989; DeStefano *et al.*, 1991; De Bruin *et al.*, 1992).

Reductive dehalogenation of some compounds also has been shown to preferentially produce specific daughter compounds. For example, during reductive dehalogenation of TCE or PCE, all three isomers of DCE can theoretically be produced; however,

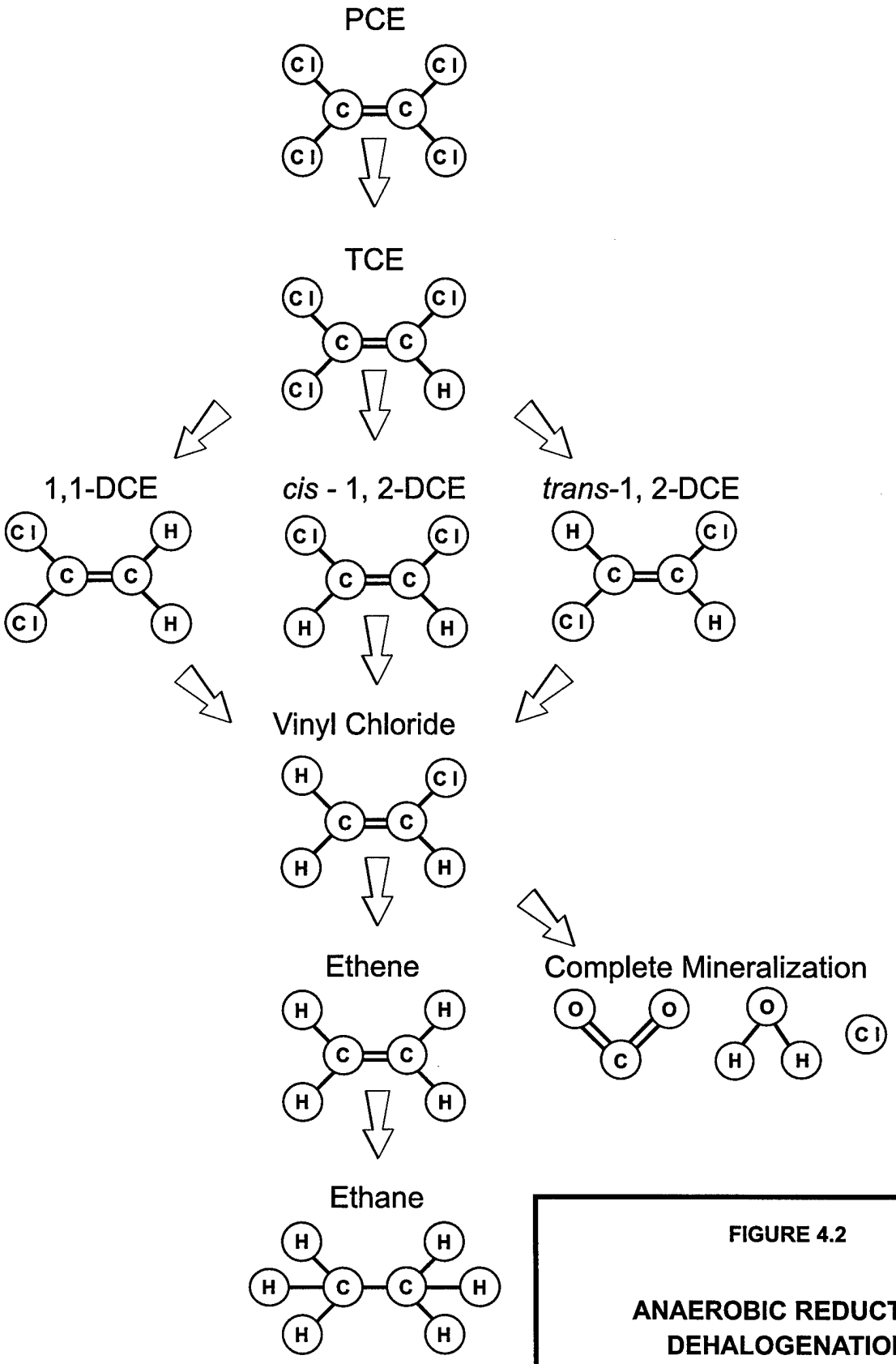

FIGURE 4.2

ANAEROBIC REDUCTIVE DEHALOGENATION

OU-4 RNA TS
Shaw AFB, South Carolina

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Denver, Colorado

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Bouwer (1994) reports that under the influence of biodegradation, *cis*-1,2-DCE is a more common intermediate than *trans*-1,2-DCE, and that 1,1-DCE is the least prevalent intermediate of the three DCE isomers.

When chlorinated compounds are used as electron acceptors, there must be an appropriate source of carbon for microbial growth in order for reductive dehalogenation to occur (Bouwer, 1994). Potential carbon sources/electron donors can include low-molecular-weight compounds (e.g., lactate, acetate, methanol, or glucose) present in natural organic matter, fuel hydrocarbons, or less-chlorinated solvents (as discussed below).

4.2.3.2 Electron Donor Reactions

Under aerobic conditions some chlorinated solvents can be utilized as the primary substrate (i.e., electron donor) in biologically mediated redox reactions (McCarty and Semprini, 1994). In this type of reaction, the facilitating microorganism obtains energy and organic carbon from the degraded compound. In contrast to reactions in which the chlorinated compound is used as an electron acceptor, only the least oxidized chlorinated solvents (e.g., VC, DCE, or chlorobenzene) may be utilized as electron donors in biologically mediated redox reactions. Also, chlorinated benzenes with up to four chlorines (i.e., CB, DCB isomers, TCB isomers, and TeCB isomers) have been shown to act as electron donors under aerobic conditions.

For example, while Murray and Richardson (1993) write that microorganisms are generally believed to be incapable of growth using TCE and PCE, other less chlorinated CAHs have been shown to be used as substrates. Davis and Carpenter (1990) describe the aerobic oxidation of VC in groundwater. McCarty and Semprini (1994) describe investigations in which VC and 1,2-DCA were shown to serve as primary substrates. These authors also document that dichloromethane has the potential to function as a primary substrate under either aerobic or anaerobic environments. Klier *et al.* (1996) describe aerobic mineralization of all three isomers of DCE. In addition, Bradley and Chapelle (1996) show evidence of oxidation of VC under iron-reducing conditions so long as there is sufficient bioavailable iron(III). CAH oxidation may be characterized by a loss of solvent mass, a decreasing molar ratio of daughter solvents to source solvent compounds, and rarely, the presence of chloromethane.

CB and polychlorinated benzenes (up to and including TeCB) have been shown to be biodegradable under aerobic conditions. Several studies have shown that bacteria are able to utilize CB (Reineke and Knackmuss, 1984), 1,4-DCB (Reineke and Knackmuss, 1984; Schraa *et al.*, 1986; Spain and Nishino, 1987), 1,3-DCB (de Bont *et al.*, 1986), 1,2-DCB (Haigler *et al.*, 1988), 1,2,4-TCB (van der Meer *et al.*, 1987; Sander *et al.*, 1991), and 1,2,4,5-TeCB (Sander *et al.*, 1991) as primary growth substrates in aerobic systems. Nishino *et al.* (1994) note that aerobic bacteria able to grow on chlorobenzene have been detected at a variety of chlorobenzene-contaminated sites, but not at uncontaminated sites. Spain (1996) notes that this provides strong evidence that the bacteria are selected for their ability to derive carbon and energy from chlorobenzene degradation *in situ*. The pathways for all of these reactions are similar, and are also similar to that of benzene (Chapelle, 1993; Spain, 1996). The only significant difference between aerobic oxidation of chlorobenzenes and benzene is the required elimination of chlorine. Anaerobic oxidation of chlorobenzenes has not been

conclusively documented, although little work has been done on the subject (Spain, 1997).

4.2.3.3 Cometabolism

When a chlorinated solvent is biodegraded through cometabolism, it serves as neither an electron acceptor nor a primary substrate in a biologically mediated redox reaction. Instead, the degradation of the compound is catalyzed by an enzyme or cofactor that is fortuitously produced by organisms for other purposes. The organism receives no known benefit from the degradation of the solvent; rather the cometabolic degradation of the solvent may in fact be harmful to the microorganism responsible for the production of the enzyme or cofactor (McCarty and Semprini, 1994).

Cometabolism is best documented for chlorinated ethenes in aerobic environments, although it potentially could occur with other chlorinated solvents or under anaerobic conditions. Aerobic degradation pathways for chlorinated ethenes are illustrated on Figure 4.3. It has been reported that under aerobic conditions chlorinated ethenes, with the exception of PCE, are susceptible to cometabolic degradation (Murray and Richardson, 1993; Vogel, 1994; McCarty and Semprini, 1994). Vogel (1994) further elaborates that the cometabolism rate increases as the degree of halogenation decreases.

In the cometabolic process, TCE is indirectly transformed by bacteria as they use BTEX or another substrate to meet their energy requirements. Therefore, TCE does not enhance the degradation of BTEX or other carbon sources, nor will its cometabolism interfere with the use of electron acceptors involved in the oxidation of those carbon sources. Given this relationship, it would follow that depletion of suitable substrates (BTEX or other organic carbon sources) likely limits cometabolism of CAHs.

4.2.3.4 Behavior of Chlorinated Solvent Plumes

Chlorinated solvent plumes can exhibit three types of behavior depending on the amount of solvent, the amount of organic (native and/or anthropogenic) carbon in the aquifer, the distribution and concentration of natural electron acceptors, and the types of electron acceptors being utilized. Individual plumes may exhibit all three types of behavior in different portions of the plume. The different types of plume behavior are summarized below.

4.2.3.4.1 Type 1 Behavior

Type 1 behavior occurs where the primary substrate is anthropogenic carbon (e.g., BTEX or landfill leachate), and this anthropogenic carbon drives reductive dechlorination. When evaluating natural attenuation of a plume exhibiting type 1 behavior the following questions must be answered:

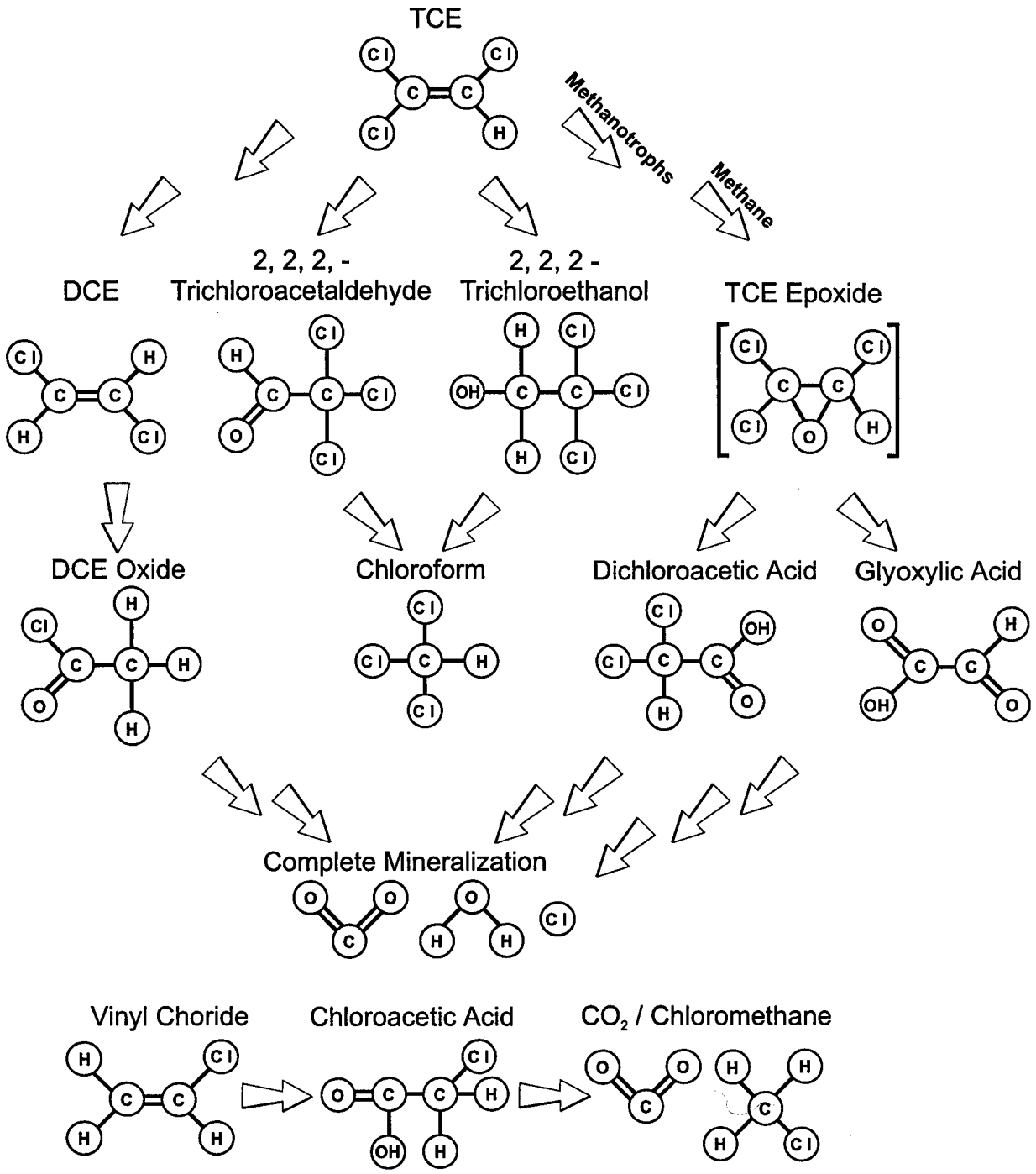

FIGURE 4.3

AEROBIC DEGRADATION

OU-4 RNA TS
Shaw AFB, South Carolina

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Denver, Colorado

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1) Is the electron donor supply adequate to allow microbial reduction of the chlorinated organic compounds? In other words, will the microorganisms "strangle" before they "starve" [i.e., will they run out of chlorinated aliphatic hydrocarbons (electron acceptors) before they run out of primary substrate (anthropogenic carbon)]?

2) What is the role of competing electron acceptors (e.g., DO, nitrate, iron(III) and sulfate)?

3) Are VC and other less-chlorinated solvents being oxidized, or are they being reduced?

Type 1 behavior results in the rapid and extensive degradation of the highly chlorinated solvents such as PCE, TCE, or polychlorinated benzenes.

4.2.3.4.2 Type 2 Behavior

Type 2 behavior dominates in areas that are characterized by relatively high concentrations of biologically available native organic carbon. This natural carbon source drives reductive dehalogenation (i.e., the primary substrate for microorganism growth is native organic carbon). When evaluating natural attenuation of a Type 2 chlorinated solvent plume, the same questions as those posed in the description of Type 1 behavior must be answered. Type 2 behavior generally results in slower biodegradation of the highly chlorinated solvents than Type 1 behavior, but under the right conditions (e.g., areas with high natural organic carbon contents), this type of behavior also can result in rapid degradation of these compounds.

4.2.3.4.3 Type 3 Behavior

Type 3 behavior dominates in areas that are characterized by low concentrations of native and/or anthropogenic carbon, and concentrations of DO that are greater than 1.0 milligram per liter (mg/L). Under these aerobic conditions reductive dehalogenation will not occur. Thus there is little or no removal of PCE and TCE. Biodegradation may proceed via the much slower process of cometabolism, but will be limited by the low concentrations of native or anthropogenic carbon. The most significant natural attenuation mechanisms for CAHs will be advection, dispersion, and sorption. However, VC can be rapidly oxidized under these conditions; DCE may be oxidized; CBs may be oxidized; and cometabolism also may occur.

4.2.3.4.4 Mixed Behavior

As mentioned above, a single chlorinated solvent plume can exhibit all three types of behavior in different portions of the plume. This can be beneficial for natural biodegradation of chlorinated solvent plumes. For example, Wiedemeier *et al.* (1996a) describe a CAH plume at Plattsburgh AFB, New York that exhibits Type 1 behavior in the source area and Type 3 behavior downgradient from the source. The best scenario involves a plume in which PCE, TCE, and DCE are reductively dehalogenated (Type 1 or Type 2 behavior), then VC is oxidized (Type 3 behavior), either aerobically or via iron reduction. VC is oxidized to carbon dioxide in this type of plume and does not

accumulate. The following sequence of reactions occurs in a plume that exhibits this type of mixed behavior:

$$PCE \rightarrow TCE \rightarrow DCE \rightarrow VC \rightarrow \text{Carbon Dioxide}$$

In general, the TCE, DCE, and VC may attenuate at approximately the same rate, and thus these reactions may be confused with simple dilution. Note that no ethene is produced during this reaction. VC is removed from the system much faster under these conditions than it is under VC-reducing conditions.

A less desirable scenario, but one in which all contaminants may be entirely biodegraded, involves a plume in which all CAHs are reductively dehalogenated via Type 1 or Type 2 behavior. VC is reduced to ethene, which may be further reduced to ethane or methane. The following sequence of reactions occur in this type of plume:

$$PCE \rightarrow TCE \rightarrow DCE \rightarrow VC \rightarrow \text{Ethene or Ethane}$$

This sequence has been investigated by Freedman and Gossett (1989). In this type of plume, VC degrades more slowly than TCE, and thus tends to accumulate.

4.2.4 Abiotic Degradation of Chlorinated Solvents

Chlorinated solvents dissolved in groundwater may also be degraded by abiotic mechanisms, although the reactions may not be complete and often result in the formation of a toxic intermediate. The most common abiotic reactions affecting chlorinated solvents are hydrolysis and dehydrohalogenation. Hydrolysis is a substitution reaction in which a halogen substituent is replaced with a hydroxyl (OH^-) group from a water molecule. Dehydrohalogenation is an elimination reaction in which a halogen is removed from a carbon atom, followed by removal of a hydrogen atom from an adjacent carbon atom, with a double bond between the carbon atoms being produced. Other possible reactions include oxidation and reduction, although Butler and Barker (1996) note that no abiotic oxidation reactions involving common halogenated solvents have been reported in the literature. They also note that reduction reactions are most commonly microbially mediated.

Hydrolysis of chlorinated methanes and ethanes has been well-demonstrated in the literature (e.g., Vogel *et al.*, 1987; Jeffers *et al.*, 1989; Vogel, 1994; Butler and Barker, 1996). The likelihood that a solvent will hydrolyze is partly dependent upon the number of halogen substituents, typically with fewer halogens resulting in more rapid hydrolysis. Dehydrohalogenation, on the other hand, is more likely to take place as the number of halogen substituents increases. One common solvent for which abiotic degradation reactions have been well-documented is 1,1,1-TCA. 1,1,1-TCA may be transformed through a series of abiotic processes (including hydrolysis) to acetic acid. Vogel and McCarty (1987) demonstrated that 1,1,1-TCA can also dehydrohalogenate to 1,1-DCE, and Jeffers *et al.* (1989) demonstrated that 1,1,2-TCA also reacts in the same manner to form 1,1-DCE. Also, once TCA is reductively dehalogenated to chloroethane, it can then hydrolyze to ethanol (Vogel and McCarty, 1987).

Butler and Barker (1996) note that attributing changes in the presence, absence, or concentration of halogenated solvents to abiotic processes is usually difficult, particularly on the field scale. Solvents may undergo both biotic and abiotic degradation, and discerning the effects of each mechanism (at the field scale), if possible, would be very difficult. Also, as Butler and Barker (1996) note, the breakdown products of some reactions such as hydrolysis (e.g., acids and alcohols) may be more easily degraded (biotically or abiotically), resulting in limited accumulation; these potentially transient products also require additional analyses that may not be feasible for a field investigation. This makes field evidence to demonstrate hydrolysis very difficult to collect and interpret, and Butler and Barker (1996) note that such evidence has not been successfully collected and presented. Evidence of dehydrohalogenation is also difficult to collect, although the presence of 1,1-DCE in conjunction with 1,1,1-TCA can provide a tentative indication that the process is ongoing, and strong evidence where it is known that no DCE was released.

4.3 DISTRIBUTION OF HYDROCARBONS AND DAUGHTER PRODUCTS

The first step for evaluating the occurrence and methods of biodegradation of chlorinated hydrocarbons and fuel hydrocarbons is to look at the distribution of target compounds and the products of biodegradation of those compounds. At many sites such as OU-4, dissolved groundwater contamination consists of a mixture of compounds, some of which may be electron donors, some of which may be electron acceptors, and some of which may be either donors or acceptors. It is therefore important to evaluate the distribution of all relevant compounds and the spatial relationships between those plumes.

For example, it is useful to determine if a source of dissolved electron donors (e.g., BTEX) coincides with a plume of dissolved contaminants that are most likely to be used as electron acceptors. The donors are needed to fuel biodegradation reactions that will either use some contaminants as electron acceptors or that will produce geochemical conditions that make the use of contaminants as electron acceptors more favorable. Also, because reductive dehalogenation is the most common biodegradation reaction involving chlorinated hydrocarbons, it is useful to look for the presence of compounds that are most likely the product of biodegradation reactions, such as *cis*-1,2-DCE or VC. These compounds are rarely released to groundwater, but are products of reductive dehalogenation. In addition, if *cis*-1,2-DCE is clearly the most common isomer of DCE, then the occurrence of reductive dehalogenation can be inferred.

The following sections present contaminant and daughter product distributions at OU-4, providing the initial evidence that dissolved fuels and chlorinated solvents are biodegrading. This evidence alone is not conclusive, but when combined with geochemical evidence presented in later sections, it is a significant indicator of biodegradation.

4.3.1 Fuel Hydrocarbons

Fuel hydrocarbons detected in groundwater at Site OU-4 include all of the BTEX compounds, as well as TMB isomers and fuel carbon. Results for fuel hydrocarbon analyses performed on samples collected in May 1997 are presented in Table 4.3, and the distribution of total BTEX is shown on Figure 4.4. Where detected, total BTEX

TABLE 4.3
GROUNDWATER QUALITY DATA SUMMARY
FOR BTEX, TMBs, AND FUEL CARBON
OU-4 RNA TS
SHAW AFB, SOUTH CAROLINA

Sample ID	Date Sampled	Benzene (µg/L)[a/]	Toluene (µg/L)	Ethyl-Benzene (µg/L)	Total Xylenes (µg/L)	Total BTEX (µg/L)	1,3,5-TMB (µg/L)	1,2,4-TMB (µg/L)	1,2,3-TMB (µg/L)	Fuel Carbon (µg/L)
MW-105	5/15/97	70.7	7.1	37.9	224.9	340.6	3.5	137	52.7	930
MW-106	5/14/97	< 1[b/]	< 1	2.6	4.1	8.7	ND[c/]	2.8	ND	14.0
MW-107	5/14/97	ND	ND	ND	ND	ND	ND	ND	ND	ND
MW-111	5/15/97	ND	ND	ND	ND	ND	ND	ND	ND	ND
MW-112	5/16/97	229	438	495	1737	2899	177	521	193	5080
MW-112A	5/16/97	ND	ND	ND	ND	ND	ND	ND	ND	ND
MW-113	5/16/97	ND	ND	< 1	1.9	2.9	ND	ND	ND	< 1
MW-114	5/15/97	6.3	12.2	56.8	219.9	295.2	14.3	74.9	20.3	623
MW-115	5/15/97	157	393	113	588	1251	26.0	191	90.7	2350
MW-115A	5/15/97	ND	ND	ND	ND	ND	ND	ND	ND	ND
MW-116	5/14/97	ND	ND	ND	ND	ND	ND	ND	ND	ND
MW-116A	5/14/97	ND	ND	ND	ND	ND	ND	ND	ND	ND
MW-117	5/15/97	30.0	89.5	72.8	396.5	588.8	13.4	90.5	41.1	1290
MW-118	5/15/97	ND	ND	ND	ND	ND	ND	ND	ND	ND
TW-101	5/14/97	ND	ND	ND	ND	ND	ND	ND	ND	ND
TW-120	5/17/97	ND	2.1	ND	ND	2.1	ND	ND	ND	1.8
TW-121	5/17/97	5.3	1.2	1	4	11.5	ND	0.9	1.2	16.1
MPA	5/16/97	14.5	943	403	1934	3294.5	152	321	206	5540
MPB	5/16/97	7.1	917	224	1101	2249.1	118	326	144	4130
MPC	5/16/97	81.7	1685	242	1279	3287.7	118	328	148	4730
MPD	5/16/97	19.3	159	142	496	816.3	40.4	204	44.9	1720
MPE	5/17/97	ND	ND	ND	2.0	2.0	ND	ND	ND	< 1
TMP-1	5/17/97	ND	ND	ND	ND	ND	ND	ND	ND	ND
TMP-2	5/17/97	12.5	2.3	2.4	4.7	21.9	0.9	4.2	9.7	127
TMP-3	5/17/97	12.4	ND	ND	2.2	14.6	ND	ND	4.5	60.4
TMP-4	5/16/97	10.1	< 1	8.4	8.5	28.0	< 1	13.2	< 1	207
TMP-5	5/16/97	28.2	9.9	77.2	128.3	243.6	19	72.3	27.7	529
SWS-1	5/15/97	ND	ND	ND	ND	ND	ND	ND	ND	ND
SWS-2	5/15/97	ND	ND	ND	ND	ND	ND	ND	ND	ND
SWS-3	5/15/97	ND	ND	ND	ND	ND	ND	ND	ND	ND
SWS-4	5/15/97	ND	ND	ND	ND	ND	ND	ND	ND	ND
SWS-5	5/15/97	ND	ND	ND	ND	ND	ND	ND	ND	ND

[a/] µg/L = micrograms/liter.

[b/] <1 = Below limit of quantitation, 1 µg/L.

[c/] ND = Analyte not detected.

concentrations ranged from 2.0 to 3,295 micrograms per liter (µg/L). Detected benzene concentrations ranged from <1 to 229 µg/L, with concentrations exceeding the USEPA (1996) maximum contaminant level (MCL) of 5 µg/L at 14 locations. Toluene concentrations ranged from <1 to 1,685 µg/L and exceeded the MCL of 1,000 µg/L at 1 location. Ethylbenzene (ranging from <1 to 403 µg/L) and xylenes (ranging from 2 to 1,934 µg/L) did not exceed MCLs at the site (Table 4.3).

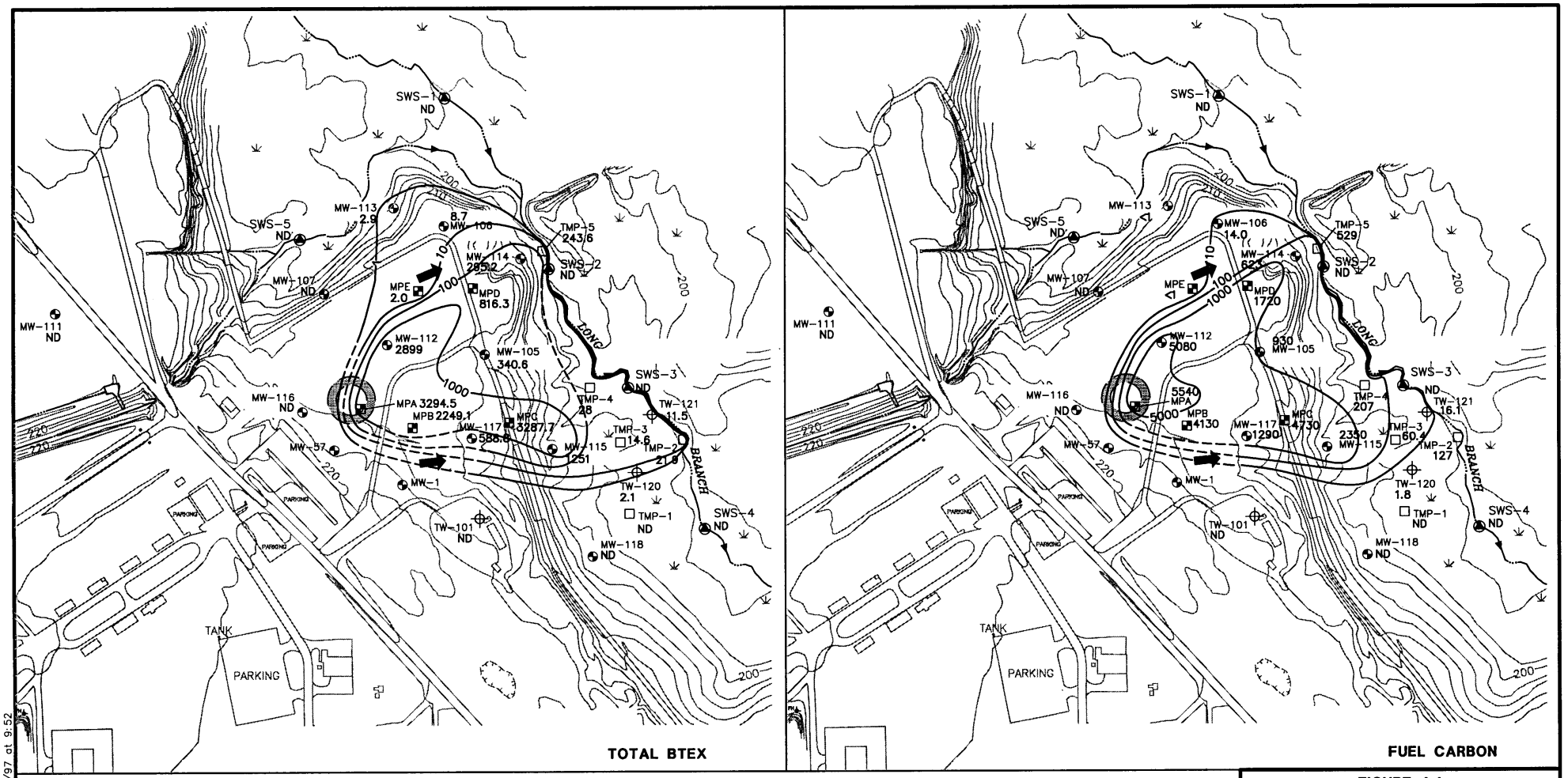
The groundwater BTEX plume is double-lobed with one lobe extending to the east/southeast and the other to the northeast. Figure 4.4 shows that groundwater BTEX concentrations are highest along the east/southeast plume lobe. Monitoring points MPA and MPC in this lobe have the two highest BTEX concentrations detected at OU-4, which coincide with two known contaminant sources at the site (MPA is in the former bermed burn pit, and MPC contained mobile LNAPL). The groundwater BTEX concentrations in the northeast plume lobe steadily decline from the fire training pit to the Long Branch Creek and suggest a single groundwater source near the fire training pit. Figure 4.5 breaks the total BTEX plume down into the individual BTEX compounds. The maximum benzene, ethylbenzene, and xylenes compounds were located along the northeastern plume lobe, whereas the maximum toluene concentration was located along the east/southeast plume lobe. Individual TMB isomers also were detected at 13 wells/points, with concentrations ranging from <1 µg/L to 328 µg/L (Table 4.3). BTEX were detected in all samples containing TMB.

The distribution of total fuel carbon (normalized to JP-4), is shown on Figure 4.4, represents the mass of fuel carbon dissolved in groundwater (fuel carbon mass was divided by approximately 0.85 to estimate TPH mass). The fuel carbon plume is similar in size and shape to the total BTEX plume. The average ratio between fuel carbon concentrations and BTEX compounds is approximately 2 to 1, indicating that BTEX comprises nearly 50 percent of the total dissolved fuel hydrocarbon concentration. Plausible fractions of BTEX dissolving from a fresh JP-4 source residing on water range from 41 to 82 percent of the total dissolved fuel hydrocarbon (Smith *et al.*, 1981).

4.3.2 Chlorinated Ethenes

Chlorinated ethenes detected in groundwater at OU-4 include PCE, TCE, DCE isomers, and VC. Data for chlorinated ethenes and other chlorinated compounds are presented in Table 4.4. May 1997 distributions of PCE, TCE, *cis*-1,2-DCE, and VC are shown on Figure 4.6.

Groundwater PCE concentrations measured in May 1997 ranged from <1 to 90.7 µg/L and exceeded the USEPA (1996) MCL of 5 µg/L at two locations. The source of PCE appears to be centered around monitoring point MPC where a fuel/solvent mobile LNAPL was observed (Section 4.1.1). PCE was not detected at monitoring point MPA located within the fire training pit. Temporary monitoring points located downgradient and near Long Branch Creek had mostly non-detectable PCE concentrations, with the exception of monitoring point TMP-2, which had a low PCE detection below the quantitation limit. PCE does not appear to be discharging to Long Branch Creek, nor was it detected at the three deep wells screened in the surficial aquifer at the site (MW-112A, -115A, and -116A). Therefore, the potential for significant receptor exposure to PCE appears to be low.



LEGEND

- MONITORING WELL
- TEMPORARY MONITORING WELL
- SURFACE WATER AND SEDIMENT SAMPLING STATION
- MONITORING POINT
- TEMPORARY MONITORING POINT
- LOCATION OF FORMER FIRE PIT BERM
- SURFACE WATER DRAINAGE
- DIRECTION OF GROUNDWATER FLOW
- —10— LINE OF EQUAL TOTAL BTEX OR FUEL CARBON CONCENTRATION (µg/L)

N

0 125 250 500
FEET

FIGURE 4.4

TOTAL BTEX AND FUEL CARBON MEASURED AT SHALLOW MONITORING WELLS/POINTS MAY 1997

OU-4 RNA TS
Shaw AFB, South Carolina

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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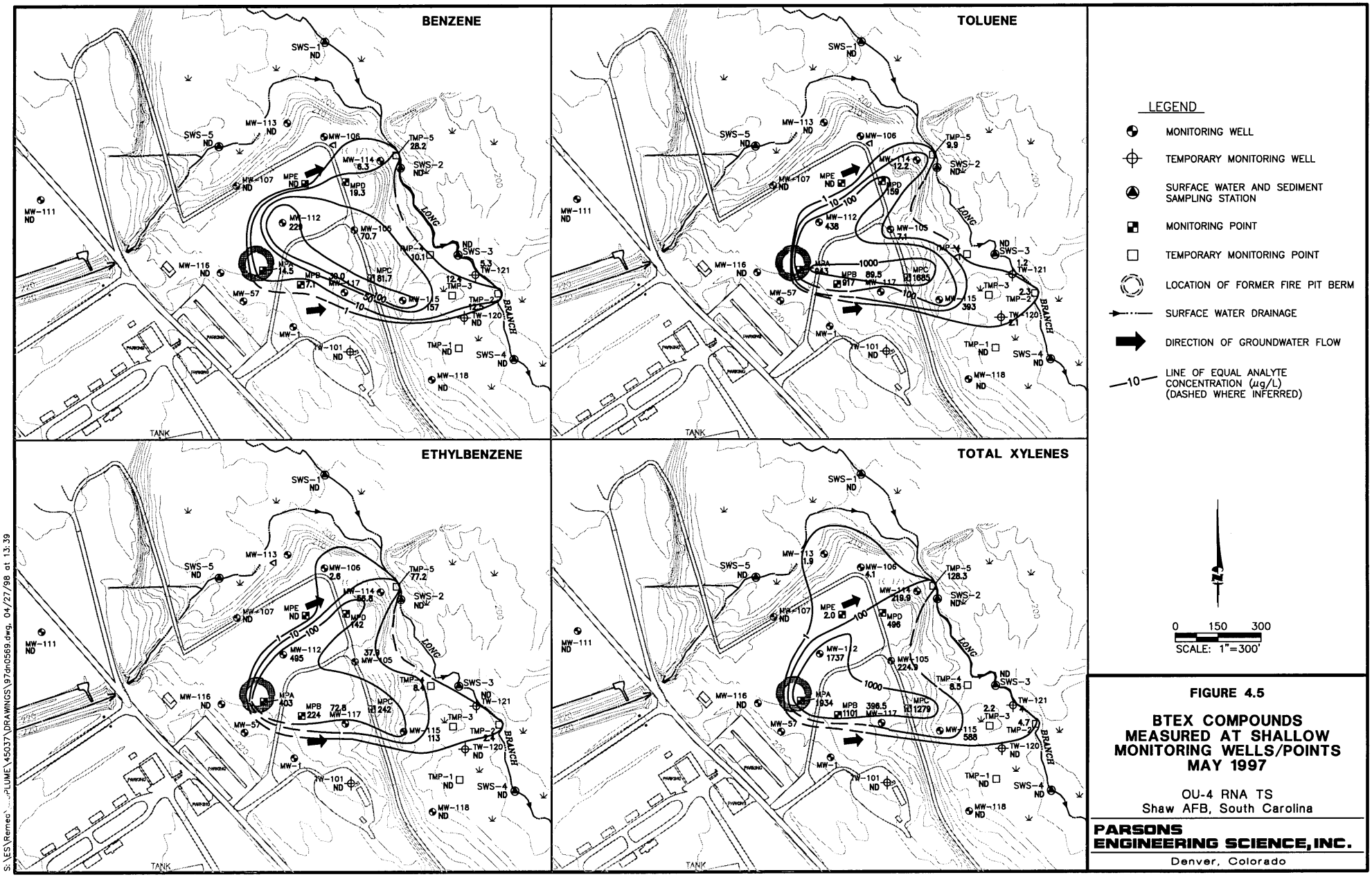

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FIGURE 4.5

BTEX COMPOUNDS MEASURED AT SHALLOW MONITORING WELLS/POINTS MAY 1997

OU-4 RNA TS
Shaw AFB, South Carolina

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

TABLE 4.4
GROUNDWATER AND SURFACE WATER QUALITY DATA SUMMARY
FOR CHLORINATED ETHENES, ETHANES, AND CHLOROFORM
OU-4 RNA TS
SHAW AFB, SOUTH CAROLINA

Sample ID	Date Sampled	PCE (µg/L)[a/]	TCE (µg/L)	cis-1,2-DCE (µg/L)	trans-1,2-DCE (µg/L)	1,1-DCE (µg/L)	Vinyl Chloride (µg/L)	1,1,1-TCA (µg/L)	1,1-DCA (µg/L)	1,2-DCA (µg/L)	Chloroform (µg/L)
MW-105	5/15/97	< 1[b/]	31.3	201	ND[c/]	< 1	1.2	ND	< 1	ND	47.9
MW-106	5/14/97	ND	ND	5.9	ND	< 1	ND	ND	3.0	ND	ND
MW-107	5/14/97	ND	ND	1.5	ND	ND	ND	ND	1.1	ND	ND
MW-111	5/15/97	ND	< 1	ND	ND	ND	ND	ND	ND	ND	ND
MW-112	5/16/97	ND	ND	22.0	ND	2.2	ND	< 1	64.8	ND	2.3
MW-112A	5/16/97	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MW-113	5/16/97	ND	ND	1.2	ND	ND	ND	ND	< 1	ND	ND
MW-114	5/15/97	ND	ND	87.1	ND	2.1	ND	ND	58.8	ND	< 1
MW-115	5/15/97	4.8	10.2	1620	ND	368	416	2030	8700[d/]	ND	< 1
MW-115A	5/15/97	ND	< 1	ND	ND	2.1	ND	ND	< 1	ND	ND
MW-116	5/14/97	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MW-116A	5/14/97	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MW-117	5/15/97	24.1	203	457	ND	148	84.6	4690[d/]	481	ND	< 1
MW-118	5/15/97	ND	ND	ND	ND	ND	ND	< 1	ND	ND	ND
TW-101	5/14/97	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
TW-120	5/17/97	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
TW-121	5/17/97	ND	ND	30.7	2.1	7.3	15.3	ND	1.5	ND	ND
MPA	5/16/97	ND	< 1	3.5	ND	4.3	ND	8.4	30.8	ND	2
MPB	5/16/97	< 1	1.3	10.6	ND	4.7	ND	411	15.4	ND	< 1
MPC	5/16/97	90.7	718	4590[d/]	ND	748	30.4	23000[d/]	1060	ND	1.2
MPD	5/16/97	ND	77.0	155	ND	1.7	ND	1.3	53.3	ND	< 1
MPE	5/17/97	ND	ND	4.9	ND	ND	ND	< 1	1.4	ND	ND
TMP-1	5/17/97	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
TMP-2	5/17/97	< 1	1.2	339	ND	116	22.8	78.6	1070	ND	ND
TMP-3	5/17/97	1.0	3.9	150	ND	40.2	59.6	60.5	1153	2.1	ND
TMP-4	5/16/97	ND	< 1	169	ND	3.5	7.7	< 1	64.9	ND	ND
TMP-5	5/16/97	ND	ND	42.5	ND	1.8	116	ND	3.5	ND	ND
SWS-1	5/15/97	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
SWS-2	5/15/97	ND	ND	< 1	ND	ND	ND	ND	ND	ND	ND
SWS-3	5/15/97	ND	ND	2.3	ND	< 1	ND	< 1	1.0	ND	ND
SWS-4	5/15/97	ND	ND	< 1	ND	ND	ND	ND	< 1	ND	ND
SWS-5	5/15/97	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

[a/] µg/L = Micrograms per Liter.

[b/] <1 = Below limit of quantitation, 1 µg/L.

[c/] ND = Analyte not detected.

[d/] Analyte values reported based on a correction for 1/10 dilution.

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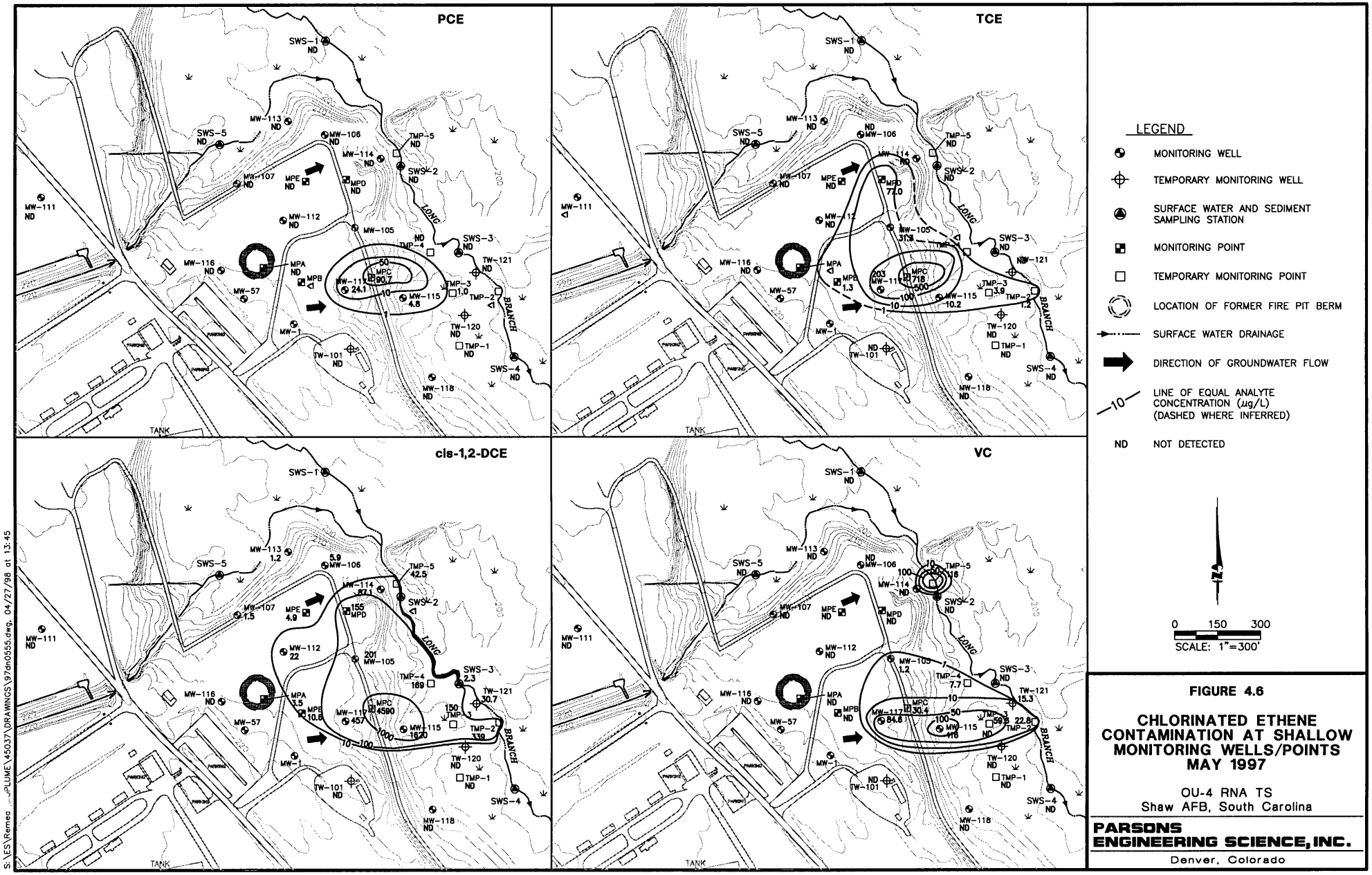

FIGURE 4.6

CHLORINATED ETHENE CONTAMINATION AT SHALLOW MONITORING WELLS/POINTS MAY 1997

OU-4 RNA TS
Shaw AFB, South Carolina

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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Groundwater TCE concentrations were slightly more widespread than PCE concentrations (Figure 4.6) and are likely the product of more than one source. The primary TCE source appears to be centered around monitoring point MPC where, like PCE, the maximum TCE concentration at the site was measured (718 µg/L). The reductive dechlorination of PCE likely contributed to the elevated TCE concentration at this location; however, TCE likely was used as a combustible solvent during fire training exercises. A second possible TCE source is located at or upgradient from monitoring point MPD. A product sheen was detected at MPD during groundwater sampling in May 1997 (Section 4.1.1). TCE does not appear to be a discharge threat to Long Branch Creek because the single highest TCE concentration measured near the creek was 1.2 µg/L at monitoring point TMP-2. TCE exceeded the USEPA (1996) MCL of 5 µg/L at five sampling locations.

The total DCE plume spanned a slightly larger area than the PCE and TCE plumes (Figure 4.6). Low DCE concentrations were measured in groundwater as far north as monitoring well MW-113 and suggest the former presence of low-level PCE and/or TCE contamination in the shallow aquifer north of the fire-training pit. The maximum DCE concentration was detected at point MPC (5,338 µg/L), where PCE and TCE contamination was also greatest. *Cis*-1,2-DCE ranged from 45 to 100 percent of the total DCE concentration (average of 85 percent). Figure 4.6 shows *cis*-1,2-DCE concentrations, which represents the majority of the DCE plume mass. The concentration ranges for the other DCE isomers were 2.1 µg/L for *trans*-1,2-DCE (measured at well TW-121 only) and <1 to 368 µg/L for 1,1-DCE. *Cis*-1,2-DCE exceeded the USEPA (1996) MCL of 70 µg/L at nine locations. 1,1-DCE exceeded the its MCL of 7 µg/L at five locations, and *trans*-1,2-DCE concentrations did not exceed its MCL. A high proportion of *cis*-1,2-DCE relative to *trans*-1,2-DCE is expected where TCE is reductively dehalogenated to DCE. A fraction of *trans*-1,2-DCE comparable to or exceeding *cis*-1,2-DCE would suggest the possibility of DCE as a source solvent because the *trans* isomer is more common when DCE is used for commercial applications. The relative abundance of *cis*-1,2-DCE is therefore a good indication that the initial reductive dehalogenation step of TCE is taking place in groundwater at Site OU-4 (Bouwer, 1994). 1,1-DCE also may result from the reductive dehalogenation of TCE, but the 1,1-DCE plume exceeding 10 µg/L coincides with and is slightly downgradient from the 1,1,1-TCA plume exceeding 10 µg/L (Section 4.3.3). Furthermore, these plumes are entirely within the east/southeast lobe of the plume, whereas elevated TCE concentrations also are present in the northeast lobe. This suggests that most of the 1,1-DCE results from dehydrohalogenation of 1,1,1-TCA.

The distribution of VC in site groundwater is shown on Figure 4.6. VC concentrations at the site ranged from 1.2 to 416 µg/L (Table 4.4). Concentrations exceeded the MCL of 2 µg/L at eight of nine locations where detected. The maximum VC concentration was detected at monitoring well MW-115, which is approximately 80 feet from the maximum concentrations of PCE, TCE, and DCE, detected at monitoring point MPC. The presence of VC in groundwater is also a good indicator of the occurrence of reductive dehalogenation, because VC is typically a gas at most working temperatures [the boiling point of VC is about 7°F (Montgomery, 1996)]. Because of this, VC is not commonly used as a solvent, but instead is used for plastic manufacturing. In addition, the low boiling point indicates that when liquid VC is

spilled, most of the mass is likely to volatilize before reaching groundwater unless there is a large-volume release.

4.3.3 Chlorinated Ethanes

Chlorinated ethanes detected in groundwater at OU-4 include 1,1,1-TCA, 1,2-DCA, and 1,1-DCA (Table 4.4). The distributions of these compounds are shown on Figure 4.7. Relatively high concentrations of 1,1,1-TCA and 1,1-DCA are present at the site, with the maximum concentrations of both compounds measured at monitoring point MPC or monitoring well MW-115. The concentration ranges of detected chlorinated ethane compounds are <1 to 23,000 µg/L for 1,1,1-TCA, <1 to 8,700 µg/L for 1,1-DCA, and a single detection of 2.1 µg/L for 1,2-DCA. The USEPA (1996) MCL of 200 µg/L for 1,1,1-TCA was exceeded at three locations. MCLs are not available for the DCA isomers. In general, chlorinated ethanes were detected in the same wells as the chlorinated ethenes.

The 1,1,1-TCA plume was centered around monitoring point MPC where a mixture of mobile LNAPL containing fuel hydrocarbons and chlorinated solvent was observed during May 1997 field work. The mobile LNAPL source was not analyzed for TCA isomers, but is the most likely source of contamination. The presence of both 1,1-DCA and fuel hydrocarbons at significant concentrations suggests that the reductive dehalogenation of 1,1,1-TCA is occurring. Additionally, 1,1-DCA is not commonly used as a solvent, whereas 1,2-DCA is; therefore, the presence of 1,1-DCA rather than 1,2-DCA (nearly absent from the site) further suggests that reductive dechlorination of 1,1,1-TCA is ongoing, particularly in the east/southeast plume lobe. The presence of 1,1-DCE was generally observed at every location where 1,1,1-TCA was detected. 1,1-DCE is the least common daughter product generated as a result of TCE dechlorination, whereas *cis*-1,2-DCE followed by *trans*-1,2-DCE are typically more commonly observed daughter products. The widespread occurrence of *cis*-1,2-DCE and absence of *trans*-1,2-DCE suggests that 1,1-DCE was not generated through the reductive dechlorination of TCE. Rather, 1,1-DCE has probably formed through the dehydrohalogenation of 1,1,1-TCA at locations where both are present. The abiotic reaction is relatively slow compared to reductive dehalogenation, which could explain why more 1,1-DCA (product of 1,1,1-TCA reductive dechlorination) than 1,1-DCE (product of 1,1,1-TCA dehydrohalogenation) was observed.

4.3.4 Chlorobenzenes

Chlorobenzenes detected in groundwater at Site OU-4 include 1,2-DCB, 1,3-DCB, 1,4-DCB, and CB (Table 4.5). These compounds generally were detected in the same wells as the other CAHs, and plumes for all four compounds appear to originate from the vicinity of MPC and migrate exclusively in the east/southeast plume lobe (Figure 4.8). The chlorobenzenes ranged in concentration from 1.7 to 117 µg/L for 1,2-DCB, <1 to 68.2 µg/L for 1,3-DCB, <1 to 14.1 for 1,4-DCB, and <1 to 9.2 µg/L for CB. The USEPA MCL for CB is 100 µg/L, the MCL for 1,2-DCB and 1,3-DCB is 600 µg/L, and the MCL for 1,4-DCB is 75 µg/L (USEPA, 1991). None of the chlorobenzenes detected at OU-4 exceeded federal MCLs.

It is possible that some DCB is being reductively dechlorinated to CB in the vicinity of MPC where conditions may be the most reducing, although little information has

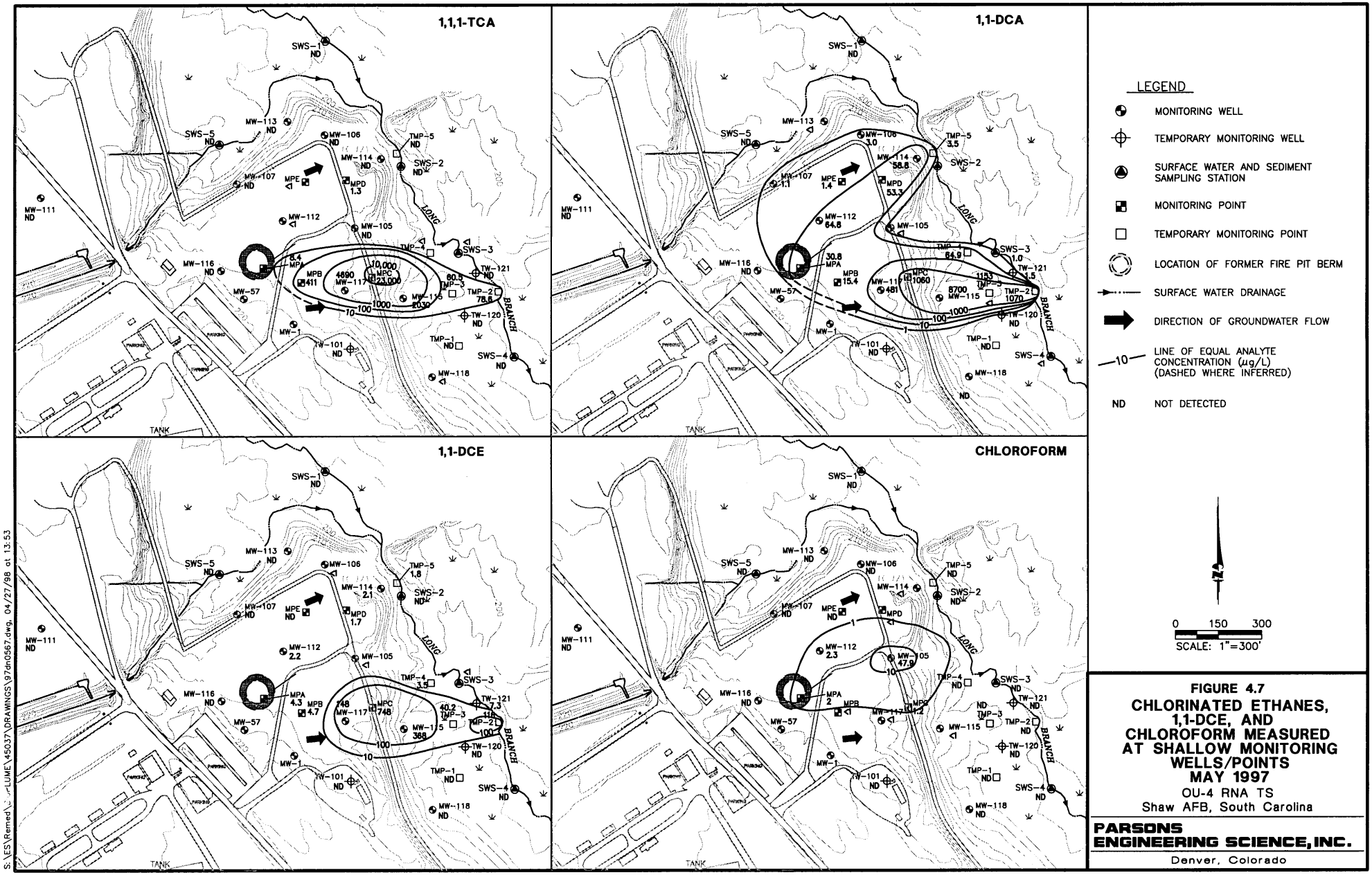

FIGURE 4.7
CHLORINATED ETHANES, 1,1-DCE, AND CHLOROFORM MEASURED AT SHALLOW MONITORING WELLS/POINTS MAY 1997
OU-4 RNA TS
Shaw AFB, South Carolina

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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TABLE 4.5
GROUNDWATER QUALITY DATA SUMMARY
FOR CHLORINATED BENZENES
OU-4 RNA TS
SHAW AFB, SOUTH CAROLINA

Sample ID	Date Sampled	Chloro-benzene (µg/L)[a/]	1,3-DCB (µg/L)	1,4-DCB (µg/L)	1,2-DCB (µg/L)	Total Chlorinated Benzenes (µg/L)
MW-105	5/15/97	ND[b/]	ND	ND	ND	0
MW-106	5/14/97	ND	ND	ND	ND	0
MW-107	5/14/97	ND	ND	ND	ND	0
MW-111	5/15/97	ND	ND	ND	ND	0
MW-112	5/16/97	ND	ND	ND	ND	0
MW-112A	5/16/97	ND	ND	ND	ND	0
MW-113	5/16/97	ND	ND	ND	ND	0
MW-114	5/15/97	ND	ND	ND	ND	0
MW-115	5/15/97	4.9	11.6	46.4	88.9	151.8
MW-115A	5/15/97	ND	ND	ND	ND	0
MW-116	5/14/97	ND	ND	ND	ND	0
MW-116A	5/14/97	ND	ND	ND	ND	0
MW-117	5/15/97	2.1	3.4	14.9	25.1	45.5
MW-118	5/15/97	ND	ND	ND	ND	0
TW-101	5/14/97	ND	ND	ND	ND	0
TW-120	5/17/97	ND	ND	ND	ND	0
TW-121	5/17/97	ND	< 1	< 1	1.7	1.7
MPA	5/16/97	ND	ND	ND	ND	0
MPB	5/16/97	< 1[c/]	1.1	16.8	13.5	31.4
MPC	5/16/97	9.2	14.1	68.2	117	208.5
MPD	5/16/97	ND	ND	ND	ND	0
MPE	5/17/97	ND	ND	ND	ND	0
TMP-1	5/17/97	ND	ND	ND	ND	0
TMP-2	5/17/97	< 1	1.8	5.6	10.5	17.9
TMP-3	5/17/97	< 1	ND	3.3	6.3	9.6
TMP-4	5/16/97	ND	< 1	2.2	2.5	4.7
TMP-5	5/16/97	ND	ND	ND	ND	0
SWS-1	5/15/97	ND	ND	ND	ND	0
SWS-2	5/15/97	ND	ND	ND	ND	0
SWS-3	5/15/97	ND	ND	ND	ND	0
SWS-4	5/15/97	ND	ND	ND	ND	0
SWS-5	5/15/97	ND	ND	ND	ND	0

[a/] µg/L = Micrograms per Liter.

[b/] ND = Analyte not detected.

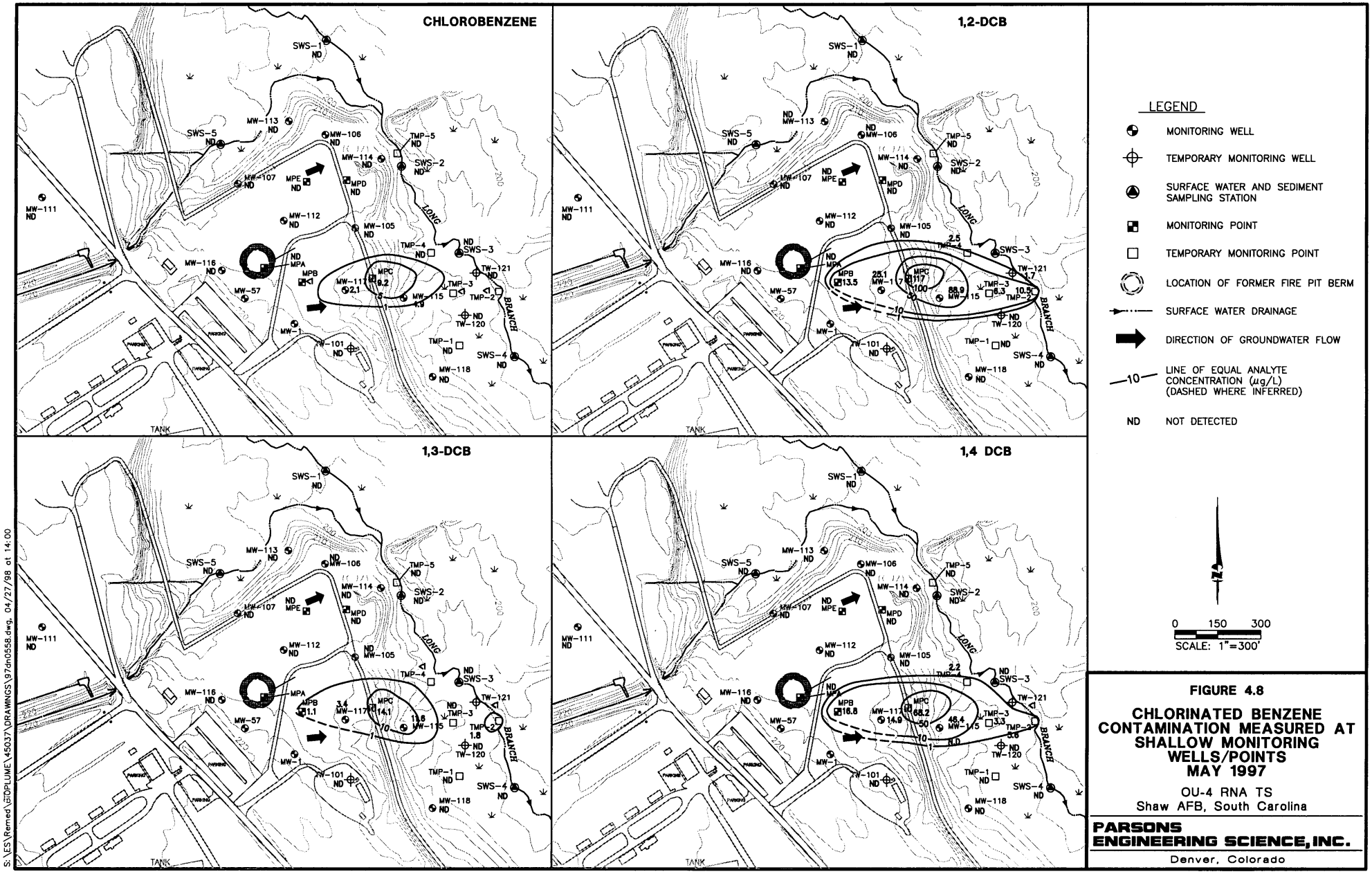

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FIGURE 4.8

CHLORINATED BENZENE CONTAMINATION MEASURED AT SHALLOW MONITORING WELLS/POINTS MAY 1997

OU-4 RNA TS
Shaw AFB, South Carolina

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

been published on this mechanism. As with chlorinated ethenes and ethanes, the degree of reductive dechlorination of chlorinated benzenes is expected to diminish with decreasing chlorination. Therefore, DCB and CB (least chlorinated of the chlorobenzenes) are least susceptible to reductive dechlorination. It is more likely that both CB and DCB reductions are being accomplished through oxidation reactions where the chlorobenzenes act as electron donors/substrates in a manner similar to BTEX biodegradation.

4.3.5 Other Chlorinated Compounds

One other chlorinated compound was detected in groundwater at Site OU-4. Chloroform was detected at concentrations of <1 to 47.9 µg/L (Table 4.4 and Figure 4.7). None of the chloroform detections exceeded the USEPA (1996) MCL of 100 µg/L. Chloroform concentrations are generally located in the area between the two primary BTEX, chlorinated ethene, and chlorinated ethane plume lobes. These same locations have relatively lower BTEX and TCE concentrations, which is reflective of being located between the two primary contaminant plume lobes. Therefore, the aquifer may be more susceptible to oxygen enrichment from precipitation and the activity of aerobic microorganisms. Chloroform can result from the aerobic oxidation of TCE and TCE daughter products (e.g., 2,2,2-trichloracetaldehyde or 2,2,2-trichloroethanol) produced during aerobic oxidation. Chloroform can also result from the reductive dechlorination of carbon tetrachloride (Criddle *et al.*, 1990). Carbon tetrachloride was not detected at the site and is not suspected to be a source of chloroform contamination. Chloroform is used in industrial cleaning operations (e.g., for cleaning circuit boards, refrigerants, or as a solvent for natural products) and its use as a combustible waste is not documented at OU-4.

4.3.6 Chloride

Chloride ions are removed from chlorinated solvents and enter solution during biodegradation, whether via reductive dehalogenation or aerobic oxidation. Therefore, chloride concentrations in groundwater should increase above background levels in areas where significant reductive dehalogenation or aerobic biodegradation is taking place. Chloride concentrations are presented in Table 4.6, and Figure 4.9 shows the May 1997 distribution of chloride in shallow groundwater at the site. Background chloride concentrations (measured in wells without contamination in shallow site groundwater) average approximately 3 mg/L. Chloride concentrations within the boundaries of the east/southeast chlorinated solvent plume lobe generally are elevated slightly above background, with a maximum concentration of 20.2 mg/L (at MW-115).

In conjunction with the distributions of CAH compounds shown on Figures 4.6 through 4.8, the elevated chloride concentrations observed at Site OU-4 are a good indication that CAHs are undergoing microbially mediated degradation. It is particularly noteworthy that the two highest chloride concentrations occur at and downgradient from MPC, where the highest CAH concentrations were detected.

TABLE 4.6
GROUNDWATER ELECTRON ACCEPTORS/BYPRODUCTS
OU-4 RNA TS
SHAW AFB, SOUTH CAROLINA

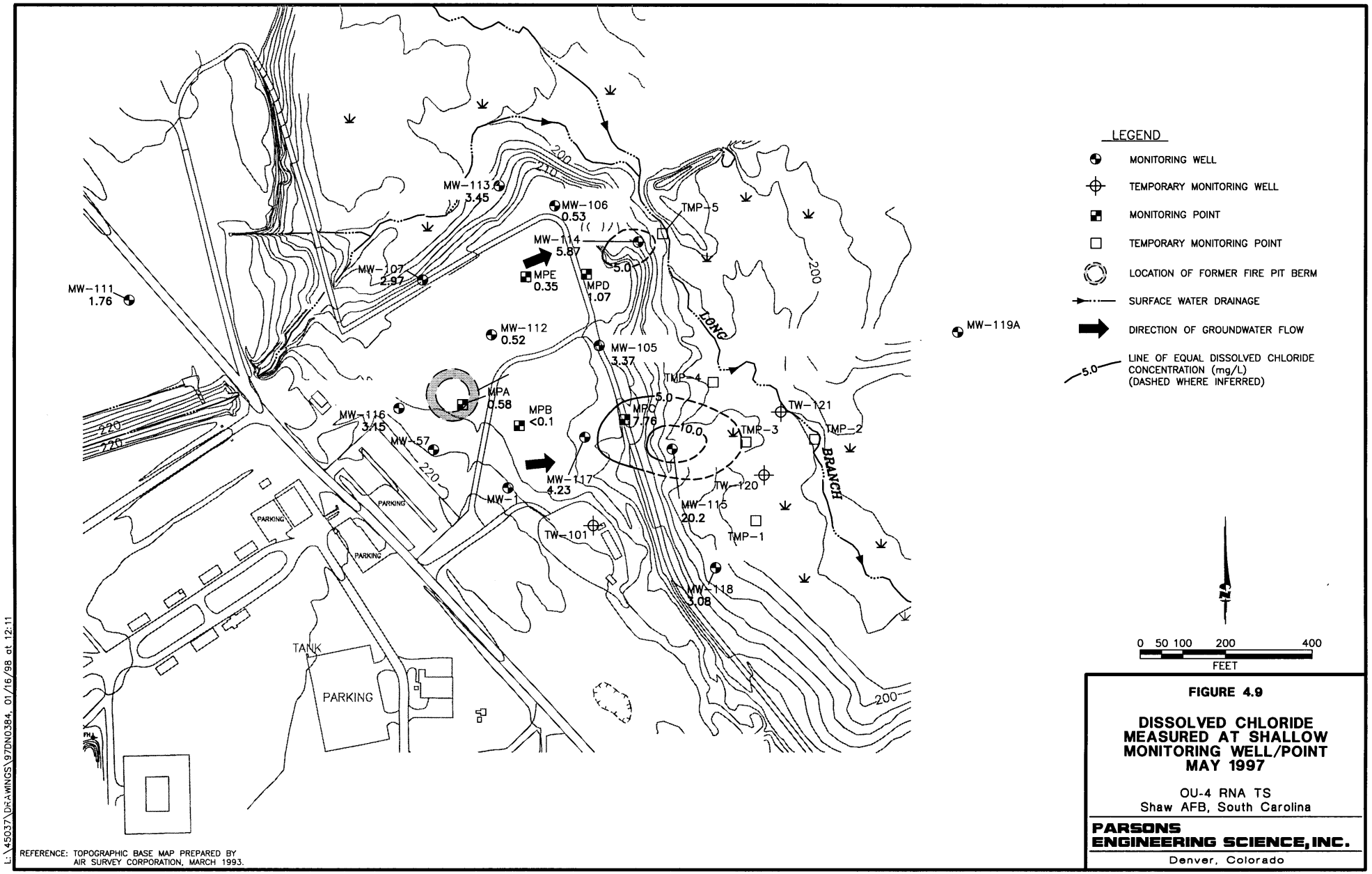
Sample ID	Date Sampled	Dissolved Oxygen (mg/L)[a/]	Carbon Dioxide (mg/L)	Chloride (mg/L)	Sulfate (mg/L)	Nitrate + Nitrite (mg/L)	Ferrous Iron (mg/L)	Hydrogen Sulfide (mg/L)	Ammonia (mg/L)	Methane (mg/L)	Ethene (mg/L)	Ethane (mg/L)
MW-105	5/15/97	0.2	88	3.37	5.57	< 0.05	3.08	< 0.1	2.18	3.59	ND[b/]	ND
MW-106	5/14/97	0.3	32	0.53	< 0.1	0.11	3.00	0.1	< 0.05	0.06	ND	ND
MW-107	5/14/97	2.7	28	2.97	4.00	0.26	1.05	< 0.1	< 0.05	0.01	ND	ND
MW-111	5/15/97	8.0	26	1.76	< 0.1	0.59	ND	< 0.1	< 0.05	ND	ND	ND
MW-112	5/16/97	<0.1	120	0.52	< 0.1	< 0.05	7.00	0.5	0.83	6.05	ND	ND
MW-112A	5/16/97	5.6	20	2.55	1.53	0.47	0.01	< 0.1	< 0.05	ND	ND	ND
MW-113	5/16/97	3.8	22	3.45	< 0.1	0.28	0.13	< 0.1	< 0.05	0.00	ND	ND
MW-114	5/15/97	0.4	36	5.87	2.75	< 0.05	2.15	0.5	< 0.05	1.14	ND	ND
MW-115	5/15/97	<0.1	84	20.2	4.30	< 0.05	5.90	0.5	1.52	2.46	0.01	0.00
MW-115A	5/15/97	7.4	22	3.92	< 0.1	0.99	0.08	< 0.1	< 0.05	ND	ND	ND
MW-116	5/14/97	8.4	18	3.15	15.1	0.99	0.04	< 0.1	< 0.05	ND	ND	ND
MW-116A	5/14/97	5.0	28	4.26	3.12	0.51	ND	< 0.1	< 0.05	ND	ND	ND
MW-117	5/15/97	9.0	44	4.23	20.4	< 0.05	0.03	< 0.1	0.26	0.33	0.00	< 0.002
MW-118	5/15/97	2.5	34	3.08	9.09	0.79	ND	< 0.1	< 0.05	0.00	ND	ND
TW-101	5/14/97	4.1	50	NA[c/]	NA	1.20	0.84	< 0.1	0.78	0.15	ND	ND
TW-120	5/17/97	0.3	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
TW-121	5/17/97	3.1	40	NA	NA	< 0.05	4.00	< 0.1	6.35	4.54	ND	0.01
MPA	5/16/97	0.5	100	0.58	< 0.1	< 0.05	4.00	0.2	7.41	6.95	ND	ND
MPB	5/16/97	0.3	28	< 0.1	3.21	< 0.05	3.00	2	1.18	3.38	ND	ND
MPC	5/16/97	0.5	70	7.76	< 0.1	< 0.05	4.00	0.3	0.43	0.07	< 0.003	0.01
MPD	5/16/97	0.5	NA	1.07	< 0.1	< 0.05	NA	NA	0.20	1.63	ND	ND
MPE	5/17/97	0.4	50	0.35	< 0.1	< 0.05	7.00	< 0.1	0.17	0.03	ND	ND
TMP-1	5/17/97	3.0	30	NA	NA	NA	0.20	< 0.1	NA	0.00	ND	ND
TMP-2	5/17/97	0.2	80	NA	NA	< 0.05	8.20	0.3	0.39	0.34	< 0.003	ND
TMP-3	5/17/97	0.2	40	NA	NA	0.41	0.18	< 0.1	< 0.05	0.19	< 0.003	ND
TMP-4	5/16/97	<0.1	50	NA	NA	0.40	4.00	0.1	0.47	0.22	ND	ND
TMP-5	5/16/97	0.1	50	NA	NA	< 0.05	4.00	< 0.1	0.37	1.71	< 0.003	ND

[a/] mg/L = milligrams per liter.

[b/] ND = Not detected.

[c/] NA = Not available.

* Note: TW-101 was mislabeled as MW-101 for nitrate+nitrite and ammonia.



REFERENCE: TOPOGRAPHIC BASE MAP PREPARED BY AIR SURVEY CORPORATION, MARCH 1993.

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FIGURE 4.9

DISSOLVED CHLORIDE MEASURED AT SHALLOW MONITORING WELL/POINT MAY 1997

OU-4 RNA TS
Shaw AFB, South Carolina

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

4.4 ADDITIONAL EVIDENCE OF BIODEGRADATION

As noted in Section 4.2, comparing concentrations and distributions of electron donors, electron acceptors, and byproducts of microbially mediated reactions can help indicate the types of processes operating at a site. In addition, other geochemical parameters, including ORP, alkalinity, and other changes in groundwater chemistry can provide supporting evidence. Volatile fatty acid concentrations also can be useful for interpreting and confirming biodegradation mechanisms.

4.4.1 Electron Donors, Native Electron Acceptors, and Byproducts

When investigating the biodegradation of hydrocarbons, it is informative to evaluate the distribution of other compounds that are used in or produced by the microbially mediated reactions that facilitate contaminant degradation. The distribution of potential electron donors other than contaminants, such as dissolved native organic carbon, is useful for evaluating the feasibility of reductive dehalogenation or cometabolism (i.e., biodegradation reactions involving another substrate). Moreover, electron acceptor and metabolic byproduct data can clarify which processes may be facilitating contaminant degradation.

4.4.1.1 Organic Carbon in Groundwater

Dissolved organic carbon can act as a source of electron donors during the reductive dehalogenation of CAHs. Dissolved TOC data from wells outside contaminant plumes can be used as an indicator of background levels of native carbon compounds.

TOC dissolved in groundwater was measured in some of the groundwater samples collected in May 1997. These concentrations are presented in Table 4.7 and shown on Figure 4.10. Dissolved TOC concentrations detected in shallow groundwater at OU-4 range from 1.05 to 144 mg/L. The highest concentration was measured at MPA, and may reflect the presence of hydrocarbon sources remaining at the fire training pit. Elsewhere, the TOC concentrations did not exceed 25.5 mg/L. Six of seven TOC concentrations above 5 mg/L were located within the contaminant plume (Figure 4.10).

TOC concentrations measured at wells that are upgradient or crossgradient from the contaminant plume (e.g., monitoring wells TW101, MW107, and MW-116) averaged approximately 1.7 mg/L and are considered representative of background. The average background concentration of dissolved TOC is noteworthy because it represents additional organic matter that is available for use as a substrate in biodegradation reactions. The background concentrations likely represent carbon dissolved from organic matter dispersed throughout the aquifer. In addition to soil TOC, this carbon source should provide a continuing source of electron donors to fuel microbial redox reactions.

4.4.1.2 Inorganic Chemistry

An interpretation of inorganic groundwater geochemistry, including isopleth maps for typical electron acceptors, can provide information regarding the relative importance of various biodegradation mechanisms and whether the conditions at the site are favorable for reductive dehalogenation of chlorinated compounds. Numerous

TABLE 4.7
GROUNDWATER GEOCHEMICAL PARAMETER ANALYTICAL DATA
OU-4 RNA TS
SHAW AFB, SOUTH CAROLINA

Sample ID	Date Sampled	Temp (°C)[a/]	pH	Conductivity (µS/cm)[b/]	Total Alkalinity (mg/L $CaCO_3$)[c/]	Redox Potential (mV)[d/]	Total Organic Carbon (mg/L)[e/]	Dissolved Hydrogen (nM)[f/]
MW-105	5/15/97	18.9	5.3	77	20	79	22.2	0.35
MW-106	5/14/97	18.1	5.8	31	20	-100	1.93	0.14
MW-107	5/14/97	17.4	5.4	26	20	99	1.66	NA[g/]
MW-111	5/15/97	19.0	4.8	19	10	222	1.37	5.79
MW-112	5/16/97	18.3	5.4	108	60	-184	22.0	3.67
MW-112A	5/16/97	18.8	5.4	19	10	200	0.884	19.02
MW-113	5/16/97	16.4	4.5	17	10	165	1.43	NA
MW-114	5/15/97	16.9	4.9	9	20	71	2.78	NA
MW-115	5/15/97	17.3	6.0	211	70	-201	8.59	0.1
MW-115A	5/15/97	19.1	4.8	24	10	196	1.06	0.3
MW-116	5/14/97	21.5	4.6	50	20	242	1.05	0.38
MW-116A	5/14/97	20.0	5.0	190	10	268	0.909	6.26
MW-117	5/15/97	19.9	4.4	62	10	319	3.72	0.1
MW-118	5/15/97	17.5	5.8	78	30	174	5.71	0.04
TW-101	5/14/97	21.8	6.2	124	50	74	2.39	1.13
TW-120	5/17/97	16.6	4.9	57	NA	60	NA	NA
TW-121	5/17/97	17.1	6.1	353	130	-65	25.5	NA
MPA	5/16/97	19.6	6.1	589	250	-56	144	NA
MPB	5/16/97	19.4	6.0	79	30	-35	5.27	NA
MPC	5/16/97	17.4	5.0	35	30	58	7.75	NA
MPD	5/16/97	18.1	5.6	43	NA	25	NA	NA
MPE	5/17/97	16.6	6.4	58	30	-7	1.51	NA
TMP-1	5/17/97	17.1	4.3	19	10	260	1.74	NA
TMP-2	5/17/97	17.8	5.1	57	20	-20	2.85	NA
TMP-3	5/17/97	16.5	4.6	40	10	255	1.76	NA
TMP-4	5/16/97	17.2	4.3	72	20	-5	2.71	NA
TMP-5	5/16/97	16.2	4.4	47	30	-30	NA	NA

[a/] °C = Degrees Celsius.

[b/] mS/cm = Microsiemens per centimeter.

[c/] $CaCO_3$ = Calcium Carbonate.

[d/] mV = Millivolts.

[e/] mg/L = Milligrams per liter.

[f/] nM = Nanomoles.

[g/] NA = Not available.

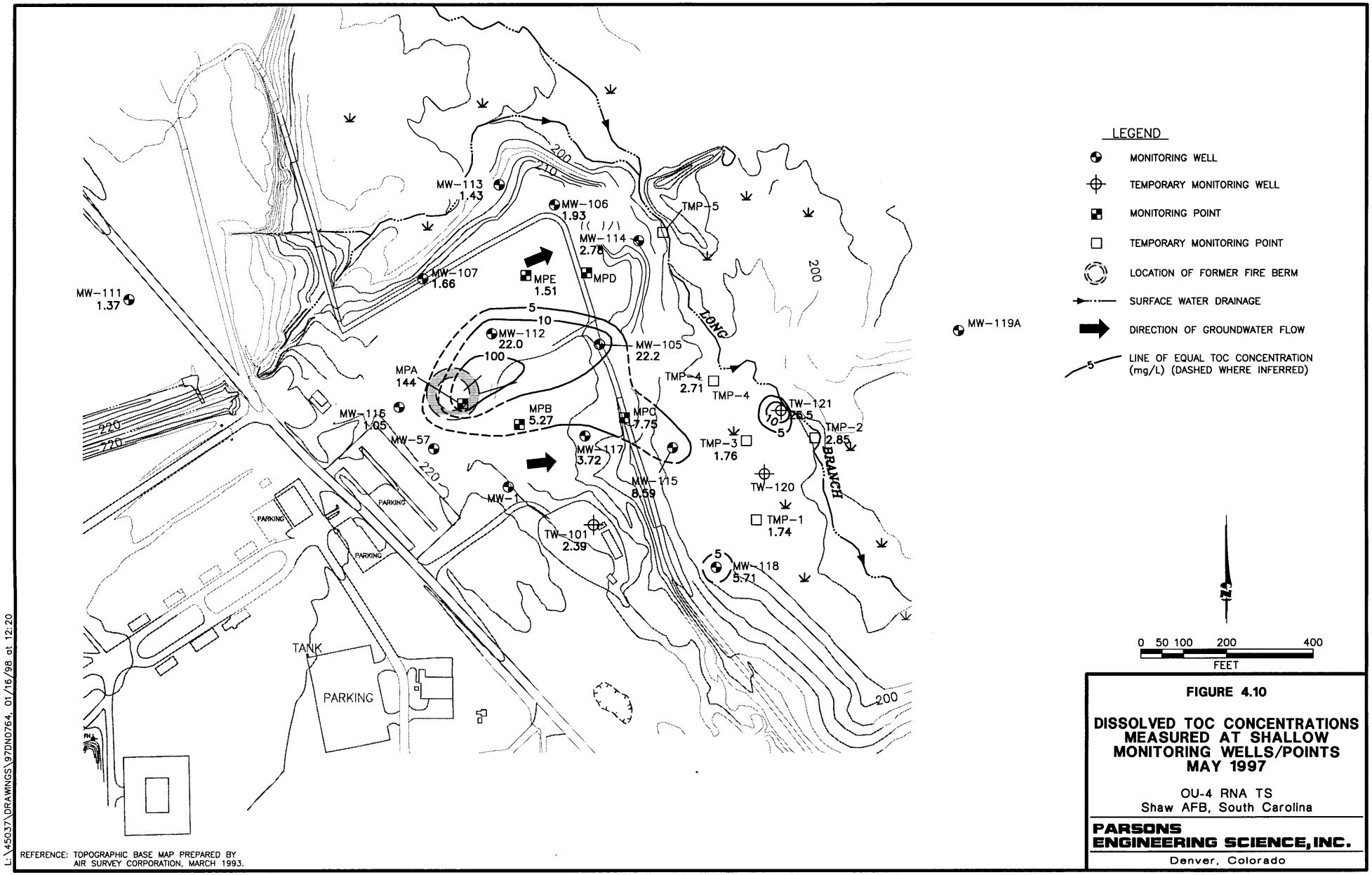

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FIGURE 4.10

DISSOLVED TOC CONCENTRATIONS MEASURED AT SHALLOW MONITORING WELLS/POINTS MAY 1997

OU-4 RNA TS
Shaw AFB, South Carolina

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geochemical parameters were evaluated in site groundwater samples. Analytical results for geochemical parameters measured in site samples are presented in Table 4.6. The following paragraphs discuss those parameters that are most useful in the evaluation of site biodegradation processes.

4.4.1.2.1 Dissolved Oxygen

DO concentrations were measured at monitoring wells and points during the May 1997 sampling event. Concentrations ranged from <0.1 to 9.0 mg/L (Table 4.6), with the highest concentrations generally measured in wells/points outside of the area of the contaminant plumes (Figure 4.11). The maximum DO concentration was measured at MW-117, which is unusual considering the presence of BTEX compounds at this location. It is possible that the chemical oxidation pilot testing performed at well MW-117 in November 1996 (IT, 1997) continued to affect groundwater chemistry in this area. At least 2,000 gallons of hydrogen peroxide was injected into monitoring well MW-117, along with quantities of ferrous sulfate and sulfuric acid to promote rapid oxidation of chlorinated compounds. Hydrogen peroxide was observed to immediately degrade upon introduction to form 0.5 mole of oxygen and 1 mole of water per mole of hydrogen peroxide degraded (IT, 1997). Therefore, the elevated DO concentration at MW-117 may be a residual effect of the pilot test.

Throughout both plume lobes, most DO concentrations were generally less than 0.5 mg/L. The low concentrations of oxygen in the plume area relative to upgradient areas is a strong indication of anaerobic biological activity in the plume area. Depletion of DO within the BTEX and chlorinated solvent plumes at Site OU-4 indicates that microbial activity stimulated by the presence of anthropogenic hydrocarbons (e.g., BTEX, chlorobenzenes, VC, DCA, and DCE) and/or natural organic carbon is depleting DO and creating anaerobic conditions.

4.4.1.2.2 Nitrate/Nitrite

Concentrations of nitrate/nitrite as nitrogen (N) were measured in groundwater samples collected in May 1997. Table 4.6 summarizes measured nitrate/nitrite (as N) concentrations, and Figure 4.11 shows the distribution of nitrate/nitrite (as N) concentrations in site groundwater. Background concentrations immediately upgradient from the plume ranged from about 0.8 mg/L to 1.2 mg/L. Within the plume, nitrate concentrations were generally less than 0.05 mg/L, whereas background concentrations averaged approximately 1.0 mg/L. The area of reduced nitrate concentrations also coincides with the area of reduced DO concentrations, indicating that as DO is removed, microbes are utilizing nitrate as an electron acceptor for degradation of organic material (such as BTEX or native organic carbon).

4.4.1.2.3 Sulfate

Sulfate concentrations were measured in groundwater samples collected in May 1997. Sulfate concentrations in shallow groundwater at the site ranged from <0.1 mg/L to 20.4 mg/L (Table 4.6). Although the sulfate concentration at background well MW-116 exceeded 15 mg/L, sulfate exhibited high variability at the site, such that any sulfate concentrations exceeding 1 mg/L could potentially be representative of background. At the core of both lobes of the contaminant plume,

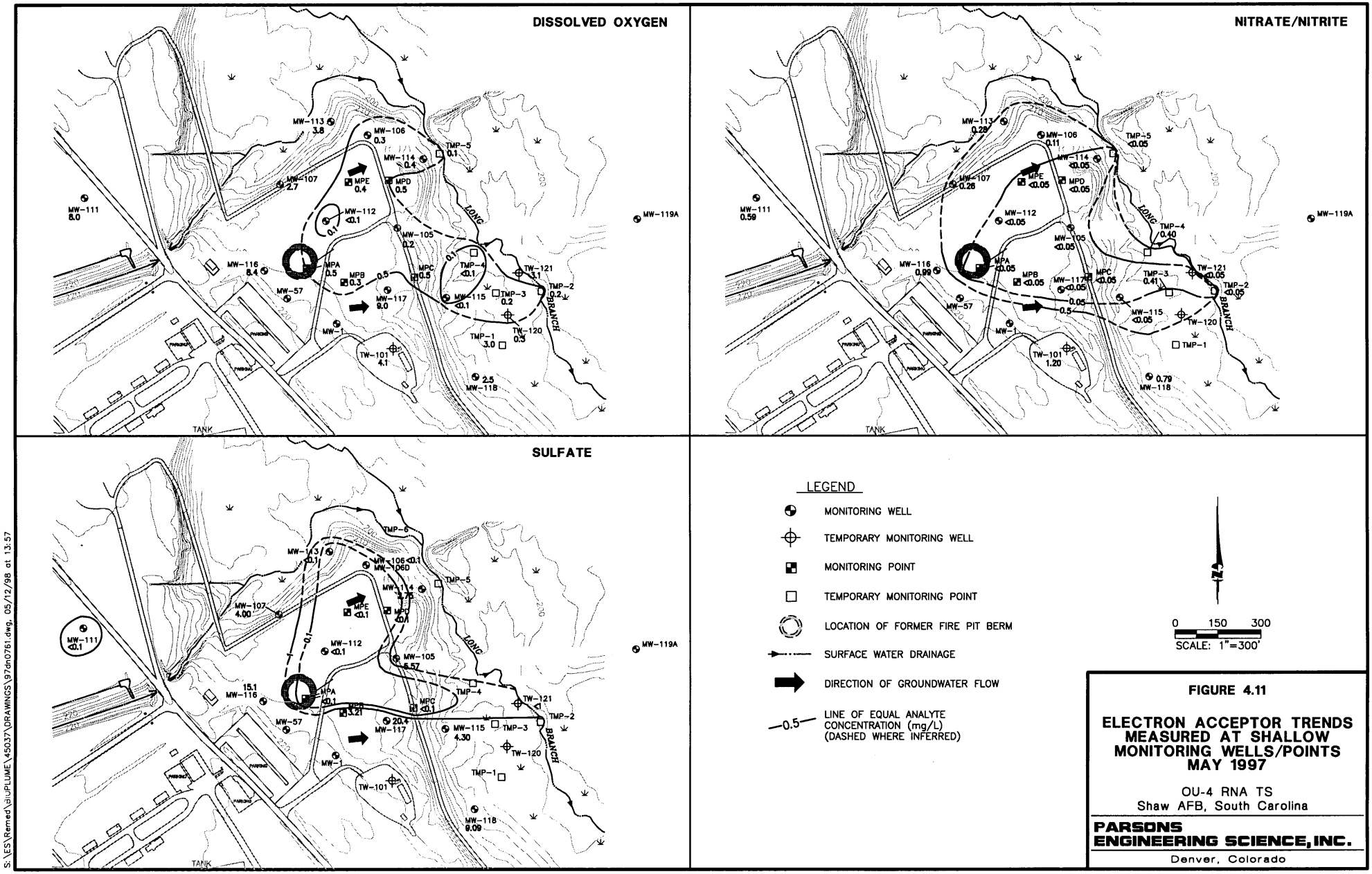

FIGURE 4.11

ELECTRON ACCEPTOR TRENDS MEASURED AT SHALLOW MONITORING WELLS/POINTS MAY 1997

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nearly all sulfate concentrations were less than 0.1 mg/L (Figure 4.11). The high sulfate concentration detected at MW-117 (20.4 mg/L) is believed to be a residual effect of the addition of sulfuric acid and ferrous sulfate during the chemical oxidation pilot test conducted at this location (IT, 1997).

The area of decreased sulfate concentrations correlates well with chlorinated solvent and BTEX concentrations. It is therefore likely that sulfate reduction is an ongoing anaerobic biodegradation process at OU-4. This is important because when a system is sufficiently reducing for sulfate reduction to occur, conditions become more favorable for reductive halogenation of chlorinated solvents.

4.4.1.2.4 Ferrous Iron

Ferrous iron [iron(II)] concentrations were measured in groundwater samples collected in May 1997. Table 4.6 summarizes ferrous iron concentrations. Measured ferrous iron concentrations range from 0.01 mg/L to 8.2 mg/L. Figure 4.12 shows the areal extent of ferrous iron in groundwater. Elevated ferrous iron concentrations coincide with both lobes of the solvent and BTEX plumes, suggesting that ferric iron hydroxide [iron(III)] is being reduced to ferrous iron during biodegradation of native organic carbon, BTEX compounds, and possibly less-chlorinated solvents. Background levels of ferrous iron average approximately 0.44 mg/L, as measured at upgradient and crossgradient wells (e.g., MW-116 and TW-101). The maximum ferrous iron concentrations (>5.0 mg/L) were detected in the vicinity of, or downgradient from, the zone of highest solvent or BTEX contamination in each of the two contaminant plume lobes (compare Figures 4.4 through 4.8 and 4.12).

Ferrous iron was not detected at elevated concentrations at MW-117 where significant chlorinated solvent and hydrocarbon contamination is present, and where large quantities of ferrous iron were added to groundwater during a chemical oxidation pilot test conducted 6 months prior to natural attenuation sampling (IT, 1997). Approximately 1,650 gallons of ferrous sulfate solution were added to the groundwater to help catalyze the oxidation of dissolved contaminants. Much of the ferrous iron likely was converted to ferric iron oxyhydroxides (Fe^{3+}) when combined with oxygen released through hydrogen peroxide degradation. Ferrous iron is known to react instantly with oxygen in the dissolved phase to form ferric iron oxyhydroxide (Chappelle, 1993).

Recent evidence suggests that the reduction of ferric iron to ferrous iron cannot proceed at all without microbial mediation (Lovley and Phillips, 1988; Lovley *et al.*, 1991; Chapelle, 1993). None of the common organic compounds found in low-temperature (i.e., non-hydrothermal), neutral, reducing groundwater could reduce ferric oxyhydroxides to ferrous iron under sterile laboratory conditions (Lovley *et al.*, 1991). This means that the reduction of ferric iron requires microbial mediation by microorganisms with the appropriate enzymatic capabilities. Because the reduction of ferric iron cannot proceed without microbial intervention, the elevated concentrations of ferrous iron that were measured in the contaminated groundwater at the site are very strong indicators of microbial activity.

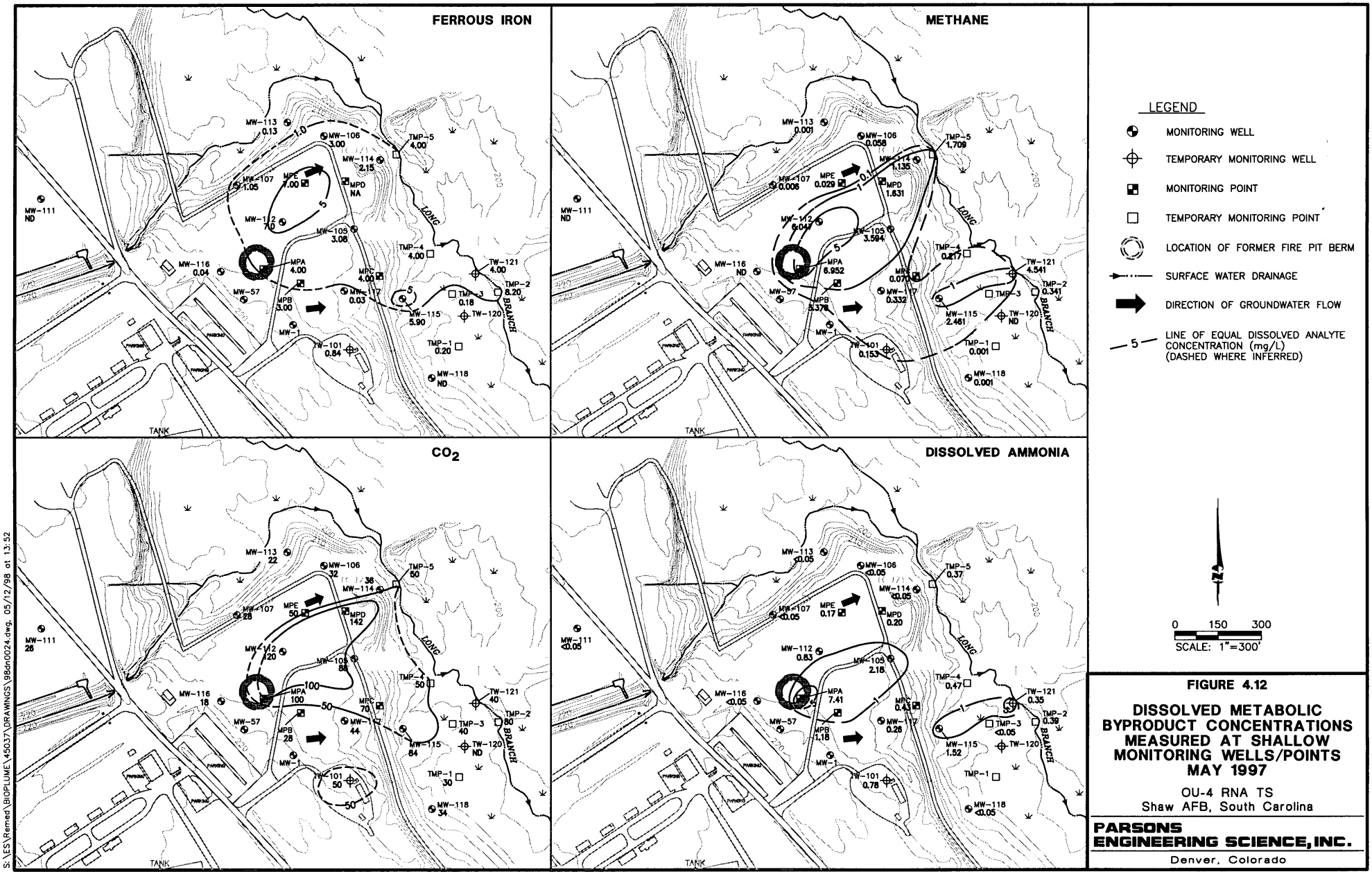

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FIGURE 4.12

DISSOLVED METABOLIC BYPRODUCT CONCENTRATIONS MEASURED AT SHALLOW MONITORING WELLS/POINTS MAY 1997

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4.4.1.2.5 Methane

Methane concentrations were measured in groundwater samples collected in May 1997. Table 4.6 lists methane concentrations, which ranged from 0.001 mg/L to 6.95 mg/L at the site. Figure 4.12 shows the distribution of methane in shallow site groundwater. The area of elevated methane concentrations correlates well with the chlorinated solvent and BTEX plumes. The presence of methane in the plume area indicates that conditions are sufficiently reducing for petroleum hydrocarbons and native organic matter to be used to support methanogenesis. Furthermore, the fact that methanogenesis is ongoing indicates that conditions in the plume area are strongly reducing, and therefore are favorable for reductive dehalogenation of chlorinated solvents.

Because methanogenesis produces more carbon dioxide than it consumes, an unlimited supply of carbon dioxide is theoretically available once the process of methanogenesis has been initiated. Therefore, methanogenesis is limited by the rate of reaction rather than the source of electron acceptors.

4.4.1.2.6 Ammonia/Ammonium

The presence of ammonia/ammonium in groundwater can result from either nitrate reduction (facilitated by microbes) or fixing of atmospheric nitrogen (also a microbial process). Therefore, the presence of ammonia/ammonium in groundwater is a strong indication of microbial activity. Figure 4.12 shows the distribution of ammonia and ammonium (as N) in groundwater at OU-4. Ammonia/ammonium concentrations ranged from below detection limits (<0.05 mg/L) to 7.41 mg/L (Table 4.6), with the area of highest concentrations coinciding with the petroleum hydrocarbon source area at the fire training pit (MPA). A second area of high concentration was detected at TW-121, and is possibly the result of natural organic matter degradation near the ditch. Notably, ammonia/ammonium is present above 1 mg/L throughout the upgradient and downgradient portions of the east/southeast lobe of the contaminant plume, yet is present at lower concentrations through the central section of the plume. This may be an effect of the chemical oxidation pilot test performed at MW-117.

Given that the highest nitrate/nitrate (as N) concentration observed in site groundwater was 1.2 mg/L and that the highest ammonia/ammonium (as N) concentration is 7.41 mg/L, the nitrogen component of the ammonia process cannot entirely be derived from nitrate and may derive from atmospheric nitrogen gas. This implies that groundwater conditions within the BTEX and solvent plumes are reducing enough to support nitrogen fixation. Stumm and Morgan (1981) note that nitrogen fixation will occur when conditions are at sufficiently reducing to support iron reduction. This process can also occur when sulfate reduction or methanogenesis is favored. Therefore, this evidence of nitrogen fixation further confirms that conditions within the solvent and BTEX plumes are sufficiently reducing to allow reductive dehalogenation to proceed. The presence of ammonium further confirms that organic matter (anthropogenic or natural) is being biodegraded in the plume area.

4.4.1.3 Ethane/Ethene in Groundwater

Ethene and ethane are the ultimate end products of the reductive dehalogenation of PCE, TCE, and 1,1,1-TCA. Concentrations of ethane and/or ethene below 0.01 mg/L were detected along the east/southeast contaminant plume lobe and at TMP-5 in the toe of the northeast contaminant plume. Figure 4.13 shows ethene and ethane distributions, and Table 4.6 lists detected concentrations. The largest concentrations of ethane and ethene emanated from the suspected source area at MPC. Although ethene and ethane occurred at very low concentrations, the presence of these compounds at and downgradient from an identified solvent source area is a strong indicator of reductive dehalogenation.

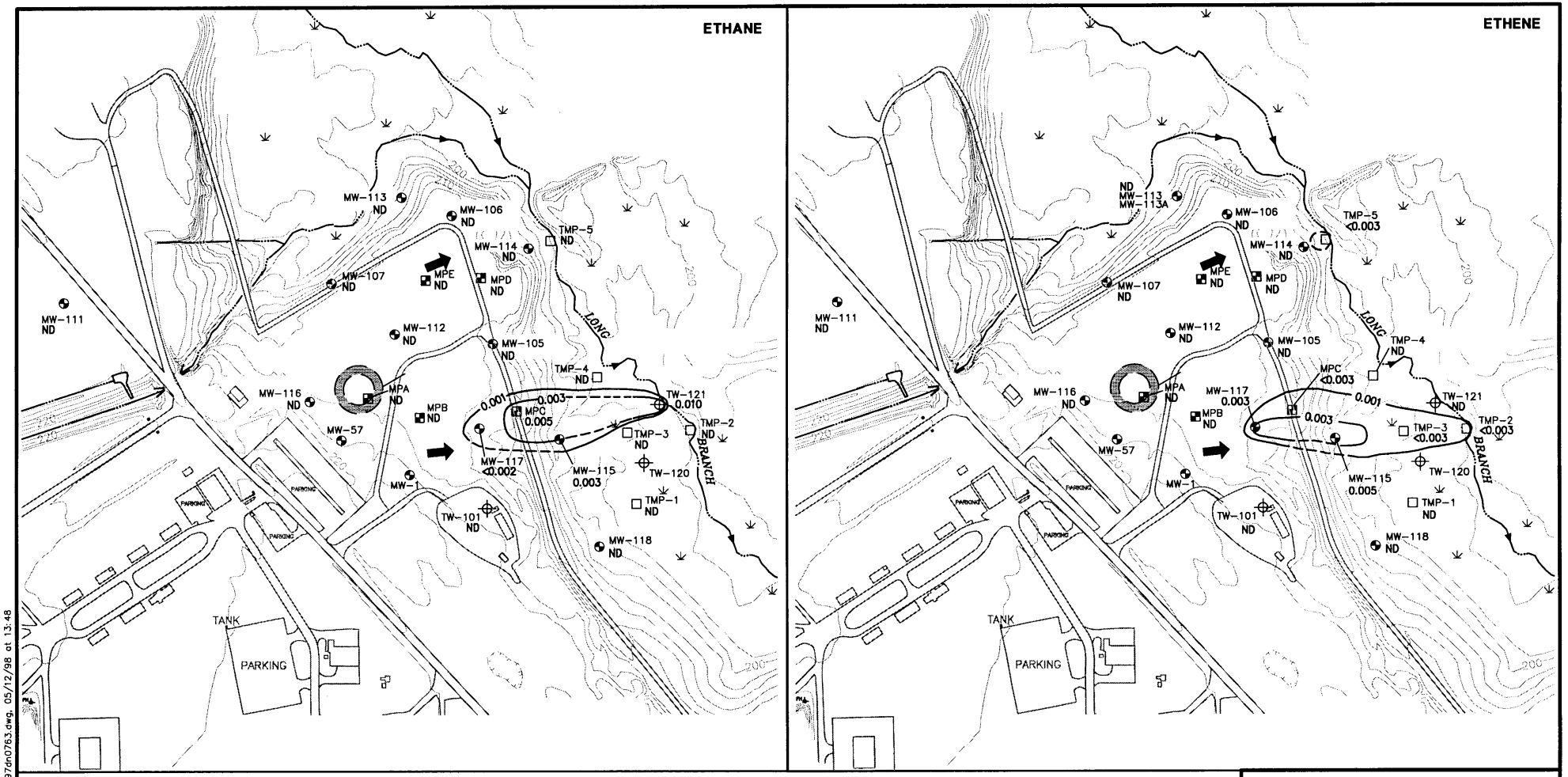
4.4.2 Additional Geochemical Indicators

Other geochemical data collected for this evaluation can be used to further interpret and support the contaminant, electron donor, electron acceptor, and byproduct data previously discussed. These parameters provide additional qualitative indications of what biodegradation processes may be operating at the site.

4.4.2.1 Oxidation/Reduction Potential and Dissolved Hydrogen as Indicators of Redox Processes

ORPs were measured at groundwater monitoring wells and points in May 1997. ORP is a measure of the relative tendency of a solution to accept or transfer electrons. The ORP of a groundwater system depends on which electron acceptors are being reduced by microbes during oxidation of organic compounds. ORPs for shallow groundwater at the site ranged from 319 millivolts (mV) to -201 mV. Table 4.7 summarizes available ORP data, and Figure 4.14 illustrate ORP trends. Low ORPs (<0 mV) coincide well with the northeast contaminant plume; ORPs below 0 are present through the upgradient and downgradient portions of the east/southeast contaminant plume. The higher ORPs through the central portion of the east/southeast contaminant plume (MPC and MW-117) may have resulted from the chemical oxidation pilot test, which caused a large release of DO (IT, 1997). Elsewhere, however, the correlation between ORP and contaminant plume extent; decreased DO, nitrate, and sulfate concentrations; and elevated ferrous iron and methane concentration is inconsistent. For example, MW-106 had a relatively low ORP (-100 mV), but relatively low BTEX and solvent concentrations were detected at this location. Unexplained inconsistencies may result from mis-measurement of ORP due to sampling error, varying instrument electrode sensitivities to different redox couples, aquifer heterogeneity, or screening over multiple aquifer subunits.

Concentrations of dissolved hydrogen (H_2) also can be used to evaluate redox processes in groundwater systems (Lovley and Goodwin, 1988; Lovley *et al.*, 1994; Chapelle *et al.*, 1995). H_2 is continuously produced in anaerobic groundwater systems by fermentative microorganisms that decompose natural and anthropogenic organic matter. This H_2 is then consumed by respiratory microorganisms that use nitrate, ferric iron, sulfate, or CO_2 as terminal electron acceptors. These nitrate-, ferric iron-, sulfate- and CO_2-reducing (methanogenic) microorganisms exhibit different efficiencies in utilizing the H_2 that is being continually produced. Nitrate reducers are highly efficient H_2 utilizers and maintain very low steady-state H_2 concentrations. Ferric iron reducers



LEGEND

- MONITORING WELL
- TEMPORARY MONITORING WELL
- MONITORING POINT
- TEMPORARY MONITORING POINT
- LOCATION OF FORMER FIRE PIT BERM
- SURFACE WATER DRAINAGE
- DIRECTION OF GROUNDWATER FLOW
- —0.001— LINE OF EQUAL ANALYTE CONCENTRATION (mg/L) (DASHED WHERE INFERRED)

N

0 125 250

SCALE: 1"=250'

FIGURE 4.13

ETHANE/ETHENE CONCENTRATIONS MEASURED AT SHALLOW MONITORING WELLS/POINTS MAY 1997

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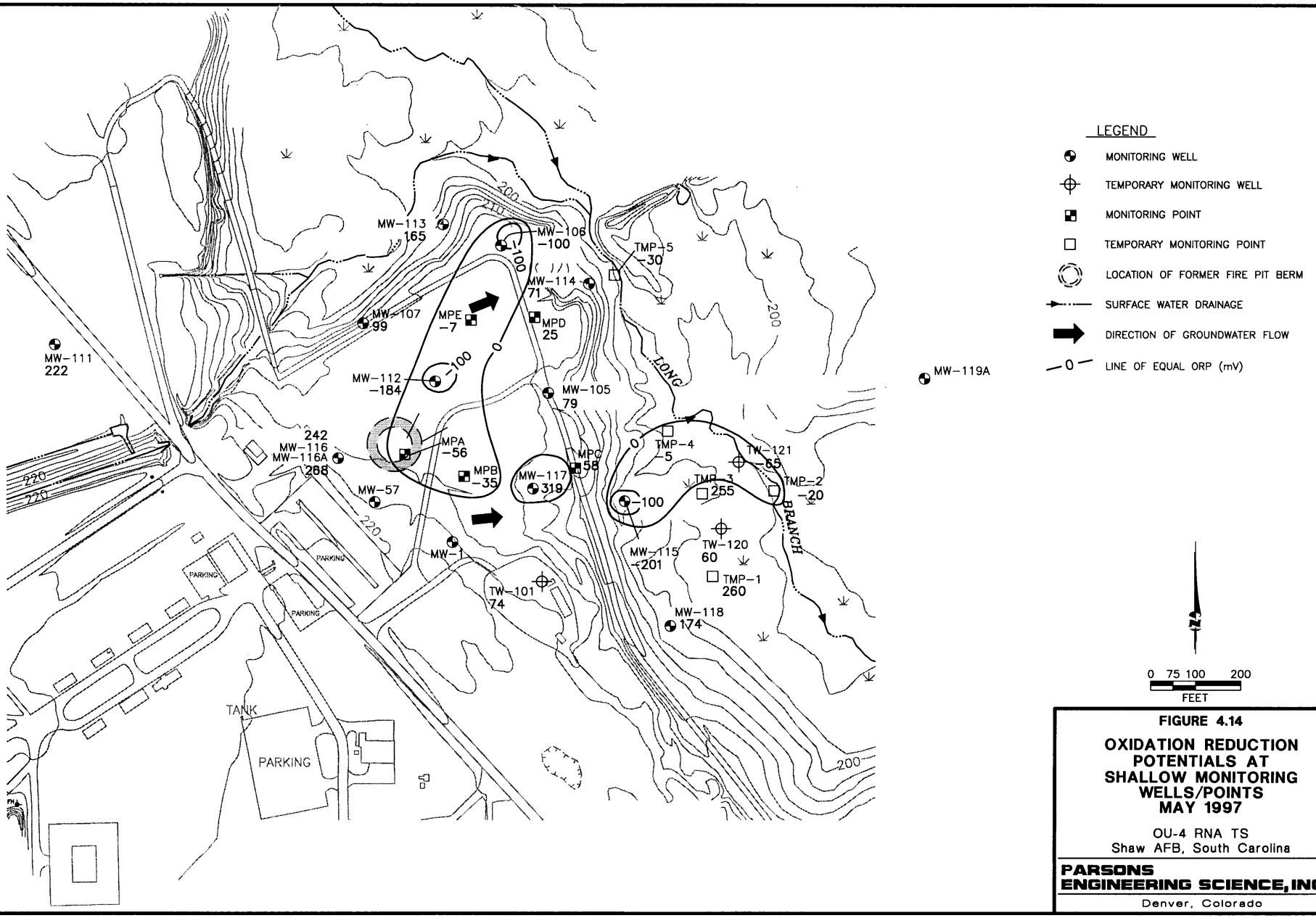

FIGURE 4.14

OXIDATION REDUCTION POTENTIALS AT SHALLOW MONITORING WELLS/POINTS MAY 1997

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are slightly less efficient and thus maintain somewhat higher H_2 concentrations. Sulfate reducers and methanogenic bacteria are progressively less efficient and maintain even higher H_2 concentrations. Because each terminal electron accepting process has a characteristic H_2 concentration associated with it, H_2 concentrations can be an indicator of predominant redox processes. These characteristic ranges are given in Table 4.8.

Dissolved H_2 concentrations measured in OU-4 groundwater in May 1997 are summarized in Table 4.7. Concentrations ranged from 0.1 nanomoles per liter (nM/L) to 5.79 nM/L at shallow monitoring wells. The two highest H_2 concentrations were measured either far upgradient of the main CAH plume at well MW-111 (5.79 nM/L) or along the northeast contaminant plume lobe at MW-112 (3.67 nM/L). The remaining H_2 values, which ranged from 0.1 to 1.13 nM/L, were obtained at wells scattered across the site, with no apparent correlation to groundwater contamination. Most elevated dissolved H_2 concentrations were not located in zones of high groundwater contamination as would be expected. The magnitude of dissolved hydrogen values at locations within the plume suggest that denitrification, ferric iron reduction, and sulfate reduction should be possible at shallow monitoring wells/point intervals in the plume. Dissolved H_2 concentrations measured in excess of 5 nM/L at the site (though not in the groundwater plume) indicate that methanogenic conditions can be achieved at the site. A dissolved hydrogen concentration of 19.02 nM/L was measured at MW-112A which is suggestive of highly reducing methanogenic conditions. No contamination was detected in monitoring well MW-112A.

TABLE 4.8
RANGE OF HYDROGEN CONCENTRATIONS FOR A GIVEN TERMINAL ELECTRON-ACCEPTING PROCESS
OU-4 RNA TS
SHAW AFB, SOUTH CAROLINA

Terminal Electron-Accepting Process	Dissolved Hydrogen Concentration (nanomoles per liter)
Denitrification	<0.1
Ferric Iron Reduction	0.2 to 0.8
Sulfate Reduction	1 to 4
Methanogenesis	5 to 20

4.4.2.2 Alkalinity and Carbon Dioxide Evolution

Carbon dioxide is produced during the biodegradation of anthropogenic and native organic carbon compounds. Carbon dioxide forms carbonic acid that dissolves carbonate minerals where present in the aquifer matrix, thereby increasing the alkalinity of the groundwater. An increase in alkalinity [measured as calcium carbonate ($CaCO_3$)] in an area with BTEX or chlorinated solvent (particularly less-chlorinated solvents)

concentrations elevated above background conditions can be used to infer that petroleum hydrocarbons, less-chlorinated solvents, or native organic carbon have been consumed through aerobic and anaerobic microbial respiration.

Total alkalinity (as $CaCO_3$) was measured in groundwater samples collected in May 1997. These measurements are summarized in Table 4.7. Alkalinity is a measure of the ability of groundwater to buffer changes in pH caused by the addition of biologically generated acids. Total alkalinity at the site varied from 10 mg/L to 250 mg/L, with many of the highest concentrations measured in wells/points corresponding to the presence of significant solvent or BTEX contamination (e.g., monitoring wells/points MW-112, MW-115, and MPA). However, alkalinity within the plume area is variable. The limited mass of carbonates is supported by a low natural groundwater alkalinity (often as low as 10 mg/L), elevated carbon dioxide concentrations within the plume as discussed below, and low groundwater pH as described in Section 4.4.2.4.

Free carbon dioxide concentrations also were measured in groundwater samples collected in May 1997 (Table 4.6). As shown on Figure 4.12, carbon dioxide concentrations within the full extent of the chlorinated solvent and BTEX plumes are noticeably elevated above background concentrations. Background concentrations are about 18 to 50 mg/L, while concentrations within the plume range from 50 to 120 mg/L. Carbon dioxide concentrations above background result from both aerobic and anaerobic biodegradation processes as contaminants are ultimately converted to carbon dioxide and water.

4.4.2.4 pH

pH was measured for groundwater samples collected from monitoring points and monitoring wells in May 1997 (Table 4.7). The pH of a solution is the negative logarithm of the hydrogen ion concentration [H^+]. The groundwater pH measured at the site ranged from 4.3 to 6.4 standard units, which is slightly below the optimal range for most microbial populations that degrade organic matter. The slightly acidic pH measurements indicates that microbial reactions and the resultant production of organic acids by microbial degradation of hydrocarbons may have an effect on groundwater pH. The moderate to low alkalinity of site groundwater is consistent with low observed pH readings, and suggests a limited capacity of groundwater to buffer the generation or organic acids. However, low pHs also were observed in upgradient wells, suggesting generally low pH readings across the entire aquifer.

4.4.2.5 Temperature

Groundwater temperature was measured at groundwater monitoring points and monitoring wells in May 1997. Table 4.7 summarizes groundwater temperature readings. Temperature can affect the types and growth rates of bacteria that can be supported in the groundwater environment, with higher temperatures typically resulting in higher growth rates. Groundwater temperatures at OU-4 varied from 16.2 degrees Celsius (°C) to 21.8°C. These relatively warm temperatures indicate that microbially-mediated biodegradation reactions should not be inhibited by overly cold groundwater temperatures, and may be enhanced.

4.5 APPROXIMATION OF BIODEGRADATION RATES

Biodegradation rate constants are necessary to accurately simulate the fate and transport of contaminants dissolved in groundwater. In many cases, biodegradation of contaminants can be approximated using first-order kinetics. First-order biodegradation rate constants may be calculated on the basis of field-scale data, or by using a small sample of the aquifer material and groundwater for microcosm studies.

For reductive dehalogenation of chlorinated compounds, first-order rates are not necessarily an accurate representation because the degradation of CAHs depends on both the concentrations of electron donors (e.g., fuel hydrocarbons or native organic material) and the concentrations of electron acceptors (including inorganic acceptors and CAHs) (Moutoux *et al.*, 1996). Second-order rates would therefore allow more accurate modeling, but at this time there are no readily available groundwater contaminant transport models that can utilize such rates. Therefore, first-order rates must be estimated for such an application.

Microcosm studies are used to show that the microorganisms necessary for biodegradation are present and to help quantify rates of biodegradation. Because microcosm studies are time consuming and expensive, they should be undertaken only at sites where there is considerable skepticism concerning the biodegradation of contaminants. The results of a microcosm study are strongly influenced by the nature of the geological material submitted for study, the physical properties of the microcosm, the sampling strategy, and the duration of the study. Biodegradation rate constants determined by microcosm studies often are much higher than those observed in the field. Microcosms are most appropriate as indicators of the potential for natural bioremediation, and to prove that losses are biological, but it may be inappropriate to use them to generate rate constants. The preferable method of contaminant biodegradation rate-constant determination is by use of field data.

In order to calculate first-order biodegradation rate constants on the field scale, the apparent degradation rate must be normalized for the effects of dilution, dispersion, and sorption. One method proposed by Buscheck and Alcantar (1995) involves interpretation of a steady-state contaminant plume and is based on the one-dimensional, steady-state analytical solution to the advection-dispersion equation presented by Bear (1979). This method can be adapted to estimate rate constants for CAHs. Another method for estimating dehalogenation rates for CAHs is described by Moutoux *et al.* (1996). This method provides a total dechlorination rate for all dechlorination steps. All rates (including the rapid TCE to DCE rate and the slow VC to ethene) are averaged together using the Moutoux *et al.* (1996) method.

The Buscheck and Alcantar (1995) and Moutoux *et al.* (1996) methods were used to estimate first-order biodegradation rate constants for BTEX and chlorinated solvents at OU-4. The methods and related calculations are summarized in Table 4.9. Decay rates

TABLE 4.9
SUMMARY OF CHLORINATED SOLVENT AND BTEX DECAY RATES
MAY 1997
OU-4 RNA TS
SHAW AFB, SOUTH CAROLINA

Analysis Method	Contaminants	Dechlorination Sequence	Sampling Date	Decay Rate (day^{-1})	Half Life (days)
B&A[a/]	Chlorinated Ethene Plume	PCE - TCE - DCE (all isomers) - VC	May 1997	1.24×10^{-2}	56
Reductive Dechlorination[b/]	Chlorinated Ethene Plume	PCE - TCE - DCE (all isomers) - VC	May 1997	2.61×10^{-3}	266
B&A	Chlorinated Ethane Plume	1,1,1-TCA - 1,1-DCA	May 1997	1.31×10^{-2}	53
Reductive Dechlorination	Chlorinated Ethane Plume	1,1,1-TCA - 1,1-DCA	May 1997	2.49×10^{-3}	213
B&A	Chlorinated Benzene Plume	1,2-DCB + 1,3-DCB + 1,4-DCB - CB	May 1997	1.13×10^{-2}	61
Reductive Dechlorination	Chlorinated Benzene Plume	1,2-DCB + 1,3-DCB + 1,4-DCB - CB	May 1997	NA	NA
B&A	BTEX Plume	NA	May 1997	1.40×10^{-2}	50
Reductive Dechlorination	BTEX Plume	NA	May 1997	NA	NA

a/ B&A = Method of Buscheck and Alcantar (1995) for steady-state plumes.

b/ Reductive Dechlorination = Method of Moutoux *et al.* (1996), which gives decay rate attributable to reductive dechlorination.

Note: The flow path chosen to calculate the biodegradation rates is MPC to MW-115 to TMP-3. The average total organic carbon content of soils was assumed to be 0.00024 mg/mg (Rust E&I, 1995) for retardation rates used in the calculation of biodegradation rates (see Appendix D).

computed using data from Site OU-4 and the Buscheck and Alcantar (1995) method were 0.014 $day^{-1}$for total BTEX, 0.012 day^{-1} for total chlorinated ethenes, 0.013 day^{-1} for total chlorinated ethane (1,1,1-TCA to DCA isomers only), 0.011 day^{-1} for dichlorobenzenes to CB. The equivalent half-lives are 50 days, 56 days, 53 days, and 61 days, respectively. Decay rates computed using the Moutoux *et al.* (1996) method indicated reductive dechlorination rates of 0.0026 day^{-1} (half-life of 266 days) for total chlorinated ethene contamination and 0.0025 day^{-1} (half-life of 213 days) for chlorinated ethane contamination.

4.6 DISCUSSION

Compounds detected in groundwater at OU-4 include BTEX, PCE, TCE, *cis*-1,2-DCE, *trans*-1,2-DCE, 1,1-DCE, VC, 1,1,1-TCA, 1,1-DCA, chloroform, 1,2-DCB, 1,3-DCB, 1,4-DCB, and CB. Of these compounds, benzene, toluene, PCE, TCE, *cis*-1,1-DCE, 1,1-DCE, VC, and 1,1,1-TCA were detected at concentrations exceeding USEPA MCLs. 1,1-DCA was detected at a maximum concentration of 8,700 µg/L, but no federal MCL is available for this compound.

The most recent comprehensive groundwater sampling event prior to groundwater sampling performed for this TS occurred between March and May 1993. Contaminant concentrations in single monitoring wells generally have fluctuated over time, with no clear trends of increasing or decreasing concentrations within the primary source area (i.e., the fire training pit). This is likely a function of the low concentrations, mixing in wells during sampling, slight differences in sampling procedures, variations in plume concentrations due to water level/flow direction changes, and/or variable rates of desorption from aquifer solids.

The additional data collected for this effort helped to define several possible additional sources of groundwater contamination in the OU-4 area. In addition to the former fire training pit, these sources include the areas around monitoring points MPB and MPC. A slight product sheen was detected at MPD, but contaminant concentration isopleths do not suggest that a significant contaminant source exists at this location. A contaminant source was identified near MW-107 during the RI; however, no groundwater contamination was detected near this location during TS sampling, and previously detected soil contamination at this location may no longer be a threat. The presence of elevated soil and groundwater contaminant concentrations between the fire training pit and MPC suggests that contamination is spread as residual and/or mobile LNAPL across a narrow 500-foot corridor between these two locations. This soil contamination likely is the result of LNAPL migration on top of the water table, smearing with water level fluctuations, or the historical use of multiple fire training locations.

Chemical and geochemical evidence indicates that the contaminants at OU-4 are being biodegraded, either as substrates or as electron acceptors. Geochemical data indicate that DO, nitrate, and sulfate are being consumed, and iron (II), methane, and ammonia/ammonium are being produced within the dissolved plume. This evidence suggests that microbial consumption of anthropogenic and natural organic matter (carbon compounds) is taking place at OU-4. Anthropogenic carbon compounds are present as petroleum hydrocarbons and less-chlorinated solvents (including, but not limited to, BTEX, CB, VC, DCE, and DCA) that are dissolved in groundwater.

Native carbon compounds include solid organic matter in the aquifer matrix and whatever portion of that matter that has dissolved into site groundwater. These compounds can serve as electron donors in redox reactions that also are consuming electron acceptors (e.g., DO, ferric iron, carbon dioxide, and chlorinated hydrocarbons) and creating byproducts [e.g., methane, iron (II), and carbon dioxide]. Plots of contaminants, electron donors, electron acceptors, and byproducts of biodegradation reactions (Figures 4.4 through 4.13) provide strong evidence of these processes.

Microbial consumption of both native and anthropogenic organic carbon compounds destroys those compounds and creates conditions favorable for reductive dehalogenation. Site chemical data provide evidence of dehalogenation of TCE, DCE, TCA, and DCA. The presence of DCE and VC in site groundwater provides the primary line of chemical evidence for reductive dehalogenation of chlorinated ethenes. In addition, the relative abundance of the *cis*-1,2 isomer of DCE relative to the *trans*-1,2 and 1,1- isomers of DCE further supports chlorinated ethene reductive dehalogenation. The presence of 1,1-DCA also suggests that 1,1,1-TCA is being reductively dehalogenated in the east/southeast plume lobe. The presence of low concentrations of ethane and ethene further indicate that conditions are sufficiently reducing for the dehalogenation processes to proceed to completion.

Elevated chloride concentrations within the solvent plumes also may indicate dehalogenation reactions, although chloride can also be produced from oxidation of less-chlorinated CAHs (i.e., utilization as a substrate). Nonetheless, elevated chloride concentrations throughout the contaminant plume support the occurrence of CAH biodegradation.

Evidence also suggests that 1,1,1-TCA is abiotically dehydrohalogenated to 1,1-DCE in the east/southeast contaminant plume lobe. It appears that 1,1-DCE concentrations coincide with significant 1,1,1-TCA concentrations, but that TCE concentrations are relatively low at these same locations. On the other hand, the presence of 1,1-DCA in wells that also contained BTEX and chlorinated ethenes suggests that reductive dechlorination of TCE and TCA is ongoing within the east/southeast contaminant plume lobe. It therefore appears that 1,1,1-TCA may be both reductively dehalogenated to 1,1-DCA and abiotically transformed to 1,1-DCE.

The ocurrence of CB and DCB contamination indicates that some reductive dechlorination of DCB may be occurring. However, DCB and CB, which are the least chlorinated of the chlorobenzenes, are also the least susceptible to reductive dechlorination. Therefore, it is possible that both CB and DCB are source solvents, and that contaminant mass reductions may be occurring through aerobic reactions where the chlorobenzenes act as electron donors/substrates in a manner similar to BTEX biodegradation.

Wiedemeier *et al.* (1996b) present a worksheet to allow an initial assessment of the prominence of reductive dehalogenation at a site. The worksheet, including the point values determined for OU-4, is included as Table 4.10. The interpretation of points awarded during the screening process is shown in Table 4.11. The score for OU-4 computed using Table 4.10 is 27, indicating that strong evidence for reductive dehalogenation of chlorinated organics is present.

TABLE 4.10
ANALYTICAL PARAMETERS AND WEIGHTING FOR PRELIMINARY SCREENING
OU-4 RNA TS
SHAW AFB, SOUTH CAROLINA

Analysis	Concentration in Most Contaminated Zone	Interpretation	Value	OU-4 Score
Oxygen	<0.5 mg/L	Tolerated, suppresses the reductive pathway at higher concentrations	3	3
Oxygen	>1 mg/L	VC may be oxidized aerobically	-3	--
Nitrate	<1 mg/L	At higher concentrations may compete with reductive pathway	2	2
Iron II	>1 mg/L	Reductive pathway possible	3	3
Sulfate	<20 mg/L	At higher concentrations may compete with reductive pathway	2	2
Sulfide	>1 mg/L	Reductive pathway possible	3	0
Methane	<0.5 mg/L >0.5 mg/L	VC oxidizes Ultimate reductive daughter product, VC Accumulates	0 3	3
Oxidation Reduction Potential (redox potential)	<50 millivolts (mV) <-100mV	Reductive pathway possible Reductive pathway likely	1 2	1
pH	5 < pH < 9 5 > pH >9	Optimal range for reductive pathway Outside optimal range for reductive pathway	0 -2	0
TOC	> 20 mg/L	Carbon and energy source; drives dechlorination; can be natural or anthropogenic	2	0
Temperature	> 20°C	At T >20°C biochemical process is accelerated	1	0
Carbon Dioxide	>2x background	Ultimate oxidative daughter product	1	1
Alkalinity	>2x background	Results from interaction of carbon dioxide with aquifer minerals	1	0
Chloride	>2x background	Daughter product of organic chlorine	2	2
Hydrogen	>1 nM	Reductive pathway possible, VC may accumulate	3	0
Hydrogen	<1 nM	VC oxidized	0	0

TABLE 4.10 (Concluded)
ANALYTICAL PARAMETERS AND WEIGHTING FOR PRELIMINARY SCREENING
OU-4 RNA TS
SHAW AFB, SOUTH CAROLINA

Analysis	Concentration in Most Contaminated Zone	Interpretation	Value	OU-4 Score
Volatile Fatty Acids	> 0.1 mg/L	Intermediates resulting from biodegradation of aromatic compounds; carbon and energy source	2	0
BTEX	> 0.1 mg/L	Carbon and energy source; drives dechlorination	2	2
PCE		Material released	0	0
TCE[a/]		Material released Daughter product of PCE	0 2 [a/]	0 0
DCE[a/]		Material released Daughter product of TCE. If cis is greater than 80% of total DCE it is likely a daughter product of TCE	0 2 [a/]	0 2
VC[a/]		Material released Daughter product of DCE	0 2 [a/]	0 2
Ethene/Ethane	>0.01mg/L >0.1 mg/L	Daughter product of VC/ethene	2 [a/] 3 [a/]	0 0
Chloroethane		Daughter product of VC under reducing conditions	2 [a/]	0
1,1,1-Trichloroethane		Material released	0	0
1,2-Dichlorobenzene		Material released	0	0
1,3-Dichlorobenzene		Material released	0	0
1,4-Dichlorobenzene		Material released	0	0
Chlorobenzene		Material released or daughter product of dichlorobenzene	2 [a/]	2
1,1-DCE		Daughter product of TCE or chemical reaction of 1,1,1-TCA	2 [a/]	2
			Total	27

a/ Points awarded only if it can be shown that the compound is a daughter product (i.e., not a constituent of the source NAPL).

TABLE 4.11
INTERPRETATION OF POINTS AWARDED DURING NATURAL ATTENUATION SCREENING
OU-4 RNA TS
SHAW AFB, SOUTH CAROLINA

Score	Interpretation
0 to 5	Inadequate evidence for biodegradation of chlorinated organics
6 to 14	Limited evidence for biodegradation of chlorinated organics
15 to 20	Adequate evidence for biodegradation of chlorinated organics
>20	Strong evidence for biodegradation of chlorinated organics

Given the available evidence, the dissolved CAH plume at OU-4 exhibits characteristics of both type 1 and type 3 behavior. Dissolved petroleum hydrocarbons and possibly some less-chlorinated solvents appear to act as carbon sources. It is likely that the introduction of petroleum hydrocarbons and solvents due to fire training activities stimulated microbial activity and made the groundwater system reducing enough to allow reductive dehalogenation of TCE, DCE, TCA, and VC. VC has been created due to dehalogenation, but it is possible that it is being oxidized (as a substrate) once it enters aerobic groundwater, especially near Long Branch Creek. Likewise, it is possible that DCE and DCA are oxidized as well. However, conclusive evidence of these oxidation processes has not been gathered. It is possible that some microbial consumption of native organic matter is taking place outside the plume and within the plume, but the DO values measured outside of the contaminant plume suggest this process is minor. Type 2 behavior may therefore be limited in extent and is not discernible at OU-4.

Maximum rates of BTEX, CB, chlorinated ethene, and chlorinated ethane degradation estimated from data collected for this investigation were 0.014 day^{-1}, 0.012 day^{-1}, 0.013 day^{-1}, and 0.011 day^{-1}, respectively. As petroleum hydrocarbons and native organic matter continue to be consumed, reductive dehalogenation of the chlorinated ethenes will continue; however, once BTEX compounds are completely degraded, the rate at which dehalogenation proceeds may slow as the microbes utilize less easily degradable fuel hydrocarbons or other organic matter.

As the type of organic matter used during biodegradation changes, the ORP conditions also may change and alter which reactions are favored. This could also affect the rates at which CAHs are reductively dehalogenated, and could also inhibit dehalogenation of some compounds. If and how this will happen is difficult to predict; the relative "degradability" of the available organic carbon and the effect of a changing electron donor source is not yet well understood. It can be stated that if conditions become more oxidizing (but not aerobic), the dehalogenation of DCE may also slow or cease. However, aerobic and/or anaerobic mineralization of VC and DCE may become more important (i.e., type 3 conditions may dominate).

SECTION 5

GROUNDWATER FLOW AND CONTAMINANT TRANSPORT MODEL

5.1 GENERAL OVERVIEW AND MODEL DESCRIPTION

In order to help predict the future migration and fate of CAHs dissolved in groundwater at OU-4, Parsons ES modeled shallow groundwater flow and the fate and transport of the dissolved CAH plume. The modeling effort had three primary objectives: 1) predict the future extent and concentrations of the dissolved contaminant plume by modeling the combined effects of advection, dispersion, sorption, and biodegradation; 2) assess the potential for downgradient receptors to be exposed to contaminants at concentrations above regulatory levels of concern; and 3) if applicable, provide technical support for the natural attenuation remedial option at post-modeling regulatory negotiations. The model was developed using site-specific data and conservative assumptions about governing physical and chemical processes. The model input data are believed to be reasonably conservative so that the actual reduction in contaminant mass caused by natural attenuation should meet or exceed model predictions.

The model codes MODFLOW (McDonald and Harbaugh, 1988) and MT3D$^{96®}$ (S.S. Papadopulos & Associates, Inc., 1996) were used to estimate the potential for dissolved CAH migration and degradation by naturally occurring mechanisms operating at the site. MODFLOW was used to generate a groundwater flow model for the site. The MODFLOW flow field was incorporated into the transport solution computed by MT3D$^{96®}$(version 1.1). The pre- and post- processors contained in Visual MODFLOW, version 2.20 (Waterloo Hydrogeologic Software, 1996) were used to facilitate model development and analysis and presentation of the model results. The MT3D$^{96®}$ code incorporates advection, dispersion, sorption, and biodegradation to simulate contaminant plume migration and degradation. MT3D$^{96®}$ uses solution routines based on the Method of Characteristics (MOC) solute transport model [e.g., as developed by Konikow and Bredehoeft (1978) for the USGS two-dimensional (2-D) MOC model code]. The MOC model was modified by Zheng (1990) to allow three-dimensional (3-D) solutions, and to allow use of a modified MOC that reduces numerical dispersion; the modified model was called MT3D. MT3D$^{96®}$ is an improvement on MT3D that allows for spatial variation of solute transport parameters (e.g., retardation and first-order decay rate).

Ideally, a code for simulating degradation of CAHs would track daughter products as well as parent compounds and allow specification of varying decay rates for each compound. Battelle National Laboratories may have developed and released such a code under the name RT3D by modifying MT3D .

5.2 CONCEPTUAL MODEL DESIGN AND ASSUMPTIONS

On the basis of the data presented in Section 3, the shallow saturated zone was conceptualized and modeled as a homogeneous, unconfined aquifer. Hydrogeologic profiles of the site (Figure 3.2) show that the major subsurface units of the aquifer are comprised of Duplin Formation terrace deposits characterized by mostly medium to very coarse sands that become finer with increasing depth. The unconfined aquifer is bounded at depth by the "100-foot clay" of the Black Creek Formation that acts as an aquitard between the shallow aquifer and the underlying Lower Black Creek Aquifer. The CAH plume is migrating primarily within the upper surface of the aquifer, as evidenced by the general lack of CAH detections at three intermediate wells at the site (MW-112A, -115A, and -116A). An observed increase in the fine and clay content of the soils begins at approximately 30 to 35 feet bgs and limits the vertical movement of contaminants between shallow and intermediate well locations.

Depth to groundwater across the site ranges from 0 to 19 feet bgs, with depth to groundwater decreasing nearer to Long Branch Creek. The configuration of groundwater elevation isopleths on Figure 3.5 indicates that groundwater in the OU-4 area primarily flows northeast and east from the fire-training burm, with discharge to Long Branch Creek east of the site and an adjoining tributary to the north of the site. The average horizontal hydraulic gradient across the study area is approximately 0.007 ft/ft; however, the groundwater gradient increases to approximately 0.11 ft/ft below the upland terrace near the creek. Vertical flow profiles indicate downward flow (0.050 to 0.077 ft/ft) at well clusters across the site.

Groundwater elevations in May 1997 (Figure 3.5) generally were lower than groundwater elevations observed during previous investigations (by approximately 2 feet); however, groundwater flow directions at the site were consistent. Therefore, it was assumed that the groundwater migration patterns interpreted from May 1997 water levels were representative of steady-state conditions. It is assumed that recharge from precipitation is substantial because annual precipitation at the Base is approximately 46 inches, the ground surface adjacent to fire training area source locations is sparsely vegetated, and sandy soils permit rapid infiltration to a relatively shallow water table (Section 3).

For the purposes of the model, it is assumed that mobile and residual LNAPL (cosolvenated CAHs and fuel hydrocarbons) contributes CAH contamination to groundwater. Although the last reported use of the fire training pit occurred in 1969, groundwater velocities are sufficiently high that a particle of contamination can travel from the fire training berm to Long Branch Creek within 2 years. Therefore, the groundwater model was calibrated with the assumption that existing LNAPL sources provide a continuous source of contaminants to groundwater. It is likely that the source will weather over time, and the mass of contaminants entering groundwater will decline.

The most important assumption made when using the MT3D$^{96®}$ code is that dispersion, sorption and biodegradation are major factors controlling contaminant fate and transport at the site. According to soil TOC data previously collected at the site (Rust E&I, 1995), concentrations of organic carbon within the site soil may provide limited contaminant sorption. Data also suggest that substantial biodegradation of

CAHs is occurring within the plume. Dispersivity, which is a characteristic of the porous medium, is a measure of the longitudinal and lateral spreading of the contaminant plume caused by local heterogeneities that cause deviations from the average linear migration velocity. The magnitude of dispersion is generally believed to be scale-dependent: the longer the plume flowpath, the greater the dispersion. Given the intercepted plume flowpath by Long Branch Creek and the rapid groundwater velocities, it is reasonable to assume that dispersion is not an important parameter influencing solute transport in the study area. Dispersion is estimated using literature values and accepted rules-of-thumb. Sorption (assumed to be a linear process) is simulated using a coefficient of retardation, and biodegradation is simulated using a first-order decay constant. Selection of values for these model input parameters is discussed in Section 5.3.3.

5.3 INITIAL MODEL SETUP

Where possible, the initial setup for this model was based on site-specific data. Where site-specific data were not available (e.g., effective porosity), reasonable assumptions were made on the basis of widely-accepted literature values for materials similar to those found in the shallow aquifer at OU-4. The following sections describe the basic model setup. Those model parameters that were varied during model calibration are discussed in Section 5.4.

5.3.1 Grid Design

The model domain for OU-4 is represented using one layer, with a 26- by 30-cell horizontal grid. Relatively small grid cells (50 feet by 50 feet) were used within the central portion of the contaminant plume to allow more accurate simulation of transport; the cell size was gradually increased with distance from the source area, with the largest cell measuring 140 feet wide by 110 feet long. The grid was oriented so that contaminant migration of the eastern plume lobe would run parallel to model rows. The grid thickness was assumed to span the elevations between 220 feet msl (general land surface elevation of the upper terrace) to 165 feet msl (approximate elevation of the geologic interface between medium to coarse and fine sands), or a model grid thickness of approximately 55 feet. The model grid covers an area of approximately 70 acres. The full extent of the model grid is indicated on Figure 5.1.

5.3.2 Groundwater Flow Model

5.3.2.1 Boundary Conditions

In defining the model domain, the area of interest must be separated from the surrounding system. Boundary conditions describe the interaction between the system being modeled and its surroundings or, for transport models, the loading of contaminant mass into the system. Boundary conditions are used to include the effects of the system outside the area being modeled with the system being modeled, while at the same time allowing the isolation of the desired model domain from the larger system. In effect, the boundaries of the model tell the area immediately inside the boundaries what to expect from the outside world. The solution of any differential equation requires specification of the conditions at the periphery of the system. Model boundaries are thus mathematical statements that specify the dependent variable (head

REFERENCE: TOPOGRAPHIC BASE MAP PREPARED BY AIR SURVEY CORPORATION, MARCH 1993.

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FIGURE 5.1

MODEL GRID

OU-4 RNA TS
Shaw AFB, South Carolina

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

TABLE 5.1
COMMON DESIGNATIONS FOR SEVERAL IMPORTANT BOUNDARY CONDITIONS[a/]
SITE OU-4 RNA TS
SHAW AFB, SOUTH CAROLINA

Boundary Condition	Boundary Type	Formal Name	General Mathematical Description	
			Groundwater Flow	Contaminant Transport
Specified-Head or Specified-Concentration	Type One	Dirichlet	$H = f(x,y,z,t)$	$C = f(x,y,z,t)$
Specified Flux	Type Two	Neumann	$\frac{\partial H}{\partial n} = f(x,y,z,t)$	$\frac{\partial C}{\partial n} = f(x,y,z,t)$
Head-Dependent or Concentration-Dependent Flux	Type Three (mixed-boundary condition)	Cauchy	$\frac{\partial H}{\partial n} + cH = f(x,y,z,t)$	$\frac{\partial C}{\partial n} + cC = f(x,y,z,t)$

[a/] Modified from Franke *et al.* (1987).

or contaminant concentration) or the flux (derivative of the head or contaminant concentration with respect to time) at the model grid boundaries.

Three types of boundary conditions generally are used to describe groundwater flow and solute transport. Boundary conditions are referred to as type one (Dirichlet), type two (Neumann), and type three (Cauchy). Table 5.1 summarizes boundary conditions for groundwater flow and solute transport.

In flow models, boundary conditions are ideally used to specify actual hydrogeologic boundaries to the system, such as streams, lakes, confining units, groundwater divides, or any geologic or anthropogenic feature that may bound a system. Also, the boundaries may be defined as areas where properties (e.g., flux) are known and can be defined. When using a numerical flow model, hydrologic boundaries such as constant-head features (e.g., lakes, etc.) or constant-flux features should, when possible, coincide with the perimeter of the model. In areas that lack obvious hydrologic boundaries, constant-head or constant-flux boundaries can be specified at the numerical model perimeter as long as the perimeter is far enough removed from the contaminant plume that transport calculations will not be affected by inaccuracies in the boundary conditions.

Specific-head cells were defined at the model boundaries. The specified heads were estimated by projecting heads from the groundwater flow maps. These constant-head cells were placed far enough from the simulated CAH plume to avoid potential boundary interferences. The MODFLOW river package was used to simulate Long Branch Creek and the adjoining tributary. Heads along Long Branch Creek were estimated to range from 200 feet msl at the northern boundary of the model domain to 191.5 feet msl at the southeastern boundary of the model domain. Heads of the adjoining tributary north of the site that feeds into Long Branch Creek were estimated

to range from 201.9 feet msl to 199.7 feet msl before connecting to Long Branch Creek. The base or lower boundary of the model is assumed to be no-flow and is set at 165 feet msl at the geologic interface of medium to coarse and fine sands. The upper model boundary is defined by the simulated water table surface.

5.3.2.2 Recharge and Evapotranspiration

Precipitation recharge is important at OU-4 because of high annual precipitation rates, sparsely vegetated terrain immediately surrounding the former fire-training pit, a relatively thin vadose zone (e.g., groundwater is at ground surface in the marshy terrain bordering Long Branch Creek), minimal surface paving, and permeable surface and subsurface geology. A recharge rate of 40 inches per year was assumed for non-forested areas at OU-4 [compared to an annual precipitation rate of 46 inches per year (Section 3)]. Because evapotranspiration is expected to increase in the forested areas at the site, a recharge rate of 12 inches per year was assumed for the forested areas east and north of the source. Appendix C shows the recharge map used for the model.

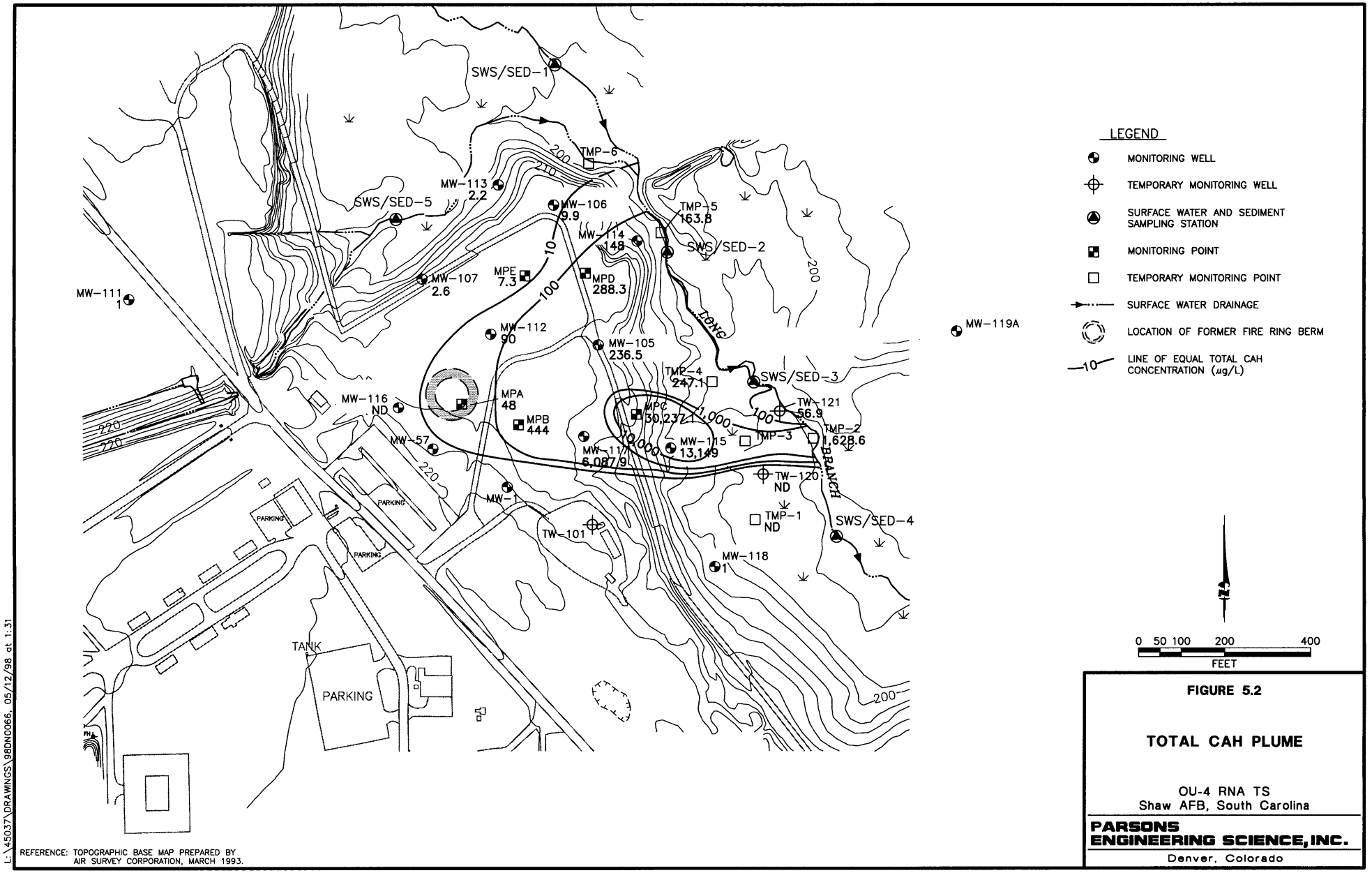
5.3.2.3 Aquifer Properties

As discussed in Section 3.3.2.3, the effective porosity is the percentage of a rock or sediment through which fluids can travel. A general value of 25 percent for effective porosity was defined for the model domain on the basis of the grain-size distribution observed in the shallow surficial aquifer (Spitz and Moreno, 1996).

Hydraulic conductivity values were calculated from field data obtained from 2 slug tests performed at monitoring wells MW-106 and MW-112, which are screened in the upper portion of the aquifer. Additional details on the slug tests are discussed in Section 3.3.2.2. It was assumed that the majority of the contaminant plume is migrating through the medium to coarse sands comprising the upper surface of the aquifer. An average hydraulic conductivity of 75 ft/day was initially defined for the model domain.

5.3.3 Contaminant Transport Model

The total dissolved CAH concentrations (combining chlorinated ethene and ethane concentrations obtained from May 1997 laboratory analytical results) for each monitoring well/point location were used as targets for model calibration. Table 4.6 presents dissolved CAH concentration data for May 1997, and Figure 5.2 shows the spatial distribution of the total dissolved CAH plume in May 1997. Predicting the natural attenuation of the total CAH plume is more appropriate than simulating the natural attenuation of a single CAH compound, such as 1,1,1-TCA. For instance, the compound 1,1-DCE results from both the reductive dehalogenation of TCE and from the dehydrohalogenation of 1,1,1-TCA. Therefore, all three compounds must be included to accurately simulate the fate and transport phenomenon of the chlorinated solvent plume. Furthermore, 1,1-DCA is the reductive dechlorination byproduct of 1,1,1-TCA and was present at a maximum concentration of 8,700 µg/L at monitoring well MW-115. 1,1-DCA currently does not have federally mandated MCLs; however, it contributes a significant amount of biodegradable chlorinated solvent mass to the groundwater system and was included in the model simulation.



REFERENCE: TOPOGRAPHIC BASE MAP PREPARED BY AIR SURVEY CORPORATION, MARCH 1993.

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FIGURE 5.2

TOTAL CAH PLUME

OU-4 RNA TS
Shaw AFB, South Carolina

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

5.3.3.1 Source

Transport models use boundary conditions to express the influence of contaminant sources such as nonaqueous-phase liquid (NAPL) bodies and dissolved mass entering through recharge, injection wells, surface water bodies, and leaking structures. Sources such as NAPL bodies may be represented as specified-concentration boundaries (limited by solubility constraints or observed maximum concentrations) or as specified-flux boundaries (for which the chemical loading rate must be known or estimated). However, in most cases, only the effects of the source are measured, not the source characteristics (Spitz and Moreno, 1996). The source must therefore be represented as a "black box" that produces appropriate contaminant concentrations or fluxes at selected points in the model. The source may be misrepresented under such a scenario, but there is often little choice in the matter. Estimating contaminant flux into groundwater from NAPL is difficult and is dependent upon several parameters, most of which cannot be measured (Feenstra and Guiguer, 1996; Abriola, 1996).

Rather than using various calculations to attempt to estimate CAH partitioning from NAPL into groundwater, the "black box" source approach was used. Experience modeling contaminated sites as part of the AFCEE Natural Attenuation Initiative has suggested that this is the best method for reproducing observed plumes. At the OU-4 site, the contaminant is assumed to enter groundwater in the study area through contact between groundwater and residual NAPL at or below the water table. Partitioning of CAHs from this source into groundwater was simulated by defining source area recharge concentrations in 15 model cells located at two known and one suspected source location at the site (Figure 5.1). The suspected source was located northeast of the fire training berm near monitoring point where a thin product sheen was detected. Low CAH concentrations upgradient of monitoring point MPD suggest that the increase in groundwater CAH concentrations at MPD were the result of contamination near this location and not from the fire training pit. The concentrations at all source locations were set at high concentrations to simulate the dissolution of current NAPL sources into the groundwater, and then adjusted (Section 5.4.2) to obtain the present observed effect.

5.3.3.2 Dispersivity

Published data summarized by Spitz and Moreno (1996) suggest that, as a rule of thumb, longitudinal dispersivity is approximately one-tenth the travel distance of the plume (from the source to the downgradient toe). For purposes of this model, dispersivity values were initially set at 50 feet which is approximately one-tenth the length of the east/southeast contaminant plume lobe where most of the groundwater contamination resides (Figure 5.2). Transverse dispersivity values were estimated as one-tenth of the longitudinal dispersivity values (Domenico and Schwartz, 1990).

5.3.3.3 Retardation

Retardation of CAHs relative to the advective velocity of the groundwater occurs when contaminant molecules are sorbed to organic carbon, silt, or clay in the aquifer matrix. Based on a measured TOC concentration of 0.00024 (Rust E&I, 1995), an assumed bulk density of 1.72 kilograms per liter (kg/L), and published values of the soil sorption coefficient (K_{oc}) for DCE, DCA, and TCA (as listed in Montgomery *et*

al., 1990) the coefficient of retardation for each contaminant was calculated. The results of these calculations are summarized in Table 5.2. The lower the assumed coefficient of retardation, the faster the CAH plume will migrate downgradient. Initially, the average calculated retardation coefficient of 1.12 was assigned to the model.

5.3.3.4 Biodegradation

As discussed in Section 4.5, first-order decay rates of 2.5×10^{-3} day^{-1} to 1.4×10^{-2} day^{-1} were calculated for CAH contamination using site-specific data. These rates were used to define a range of possible values for model input. An estimate of 5.5×10^{-3} $days^{-1}$ was defined for the model domain. Also as noted in Section 4.5, reductive dechlorination of CAHs may be best represented using a second-order rate, but most common transport codes (including MT3D[96]) can incorporate only a first-order rate. This impacts model calibration and may constrain the usefulness of predictions, but at this time there is no feasible alternative for simulating CAH transport under the influence of biodegradation. Provided that conservative values are used for other input parameters and a sensitivity analysis is performed, simulations incorporating a first-order rate constant will still be useful and meaningful.

5.4 MODEL CALIBRATION

Model calibration is an important component in the development of any numerical groundwater model. Calibration of the flow model demonstrates that the model is capable of matching hydraulic conditions observed at the site; calibration of a contaminant transport model superimposed upon the calibrated flow model helps demonstrate that contaminant loading and transport conditions are being appropriately simulated. Model input and output are included in Appendix D.

5.4.1 Groundwater Flow Model

Groundwater elevation data collected in May 1997 and presented on Figure 3.5 were used to calibrate the flow model. Water level elevation data from 11 monitoring wells were used to compare measured and simulated heads for calibration. The selected locations were TW-101, MW-105, MW-106, MW-107, MW-112, MW-113, MW-114, MW-115, MW-116, MW-117, and MW-118.

The numerical flow model was calibrated by altering hydraulic conductivity, constant-head elevations at the model boundaries, and the river package parameters in a trial-and-error fashion until simulated heads approximated observed field values within a prescribed accuracy. Figure 5.3 shows the calibrated water table. Calibrated model hydraulic conductivities ranged between 10 and 75 ft/day, with most cells having a hydraulic conductivity of 75 ft/day.

The root mean squared (RMS) error is commonly used to express the average difference between simulated and measured heads. RMS error is the average of the squared differences between measured and simulated heads, and can be expressed as:

TABLE 5.2
CALCULATION OF RETARDATION COEFFICIENTS (Foc = 0.00024)
OU4 RNA TS
SHAW AFB, SOUTH CAROLINA

Compound	Molecular Weight	K_{oc} (L/kg [a/])	Fraction Organic Carbon [b/]	Distribution Coefficient K_d (L/kg)	Distribution Coefficient K_d (ft^3/kg)	Bulk Density (kg/L)[c/]	Bulk Density (kg/ft^3)	Effective Porosity [d/]	Coefficient of Retardation
PCE	167.85	263	0.00024	0.063	0.00223	1.72	48.70	0.25	1.43
TCE	131.39	107	0.00024	0.026	0.00091	1.72	48.70	0.25	1.18
1,1-DCE	96.94	65	0.00024	0.016	0.00055	1.72	48.70	0.25	1.11
cis-1,2-DCE	96.94	65	0.00024	0.016	0.00055	1.72	48.70	0.25	1.11
trans-1,2-DCE	96.94	59	0.00024	0.014	0.00050	1.72	48.70	0.25	1.10
VC	62.5	2	0.00024	0.001	0.00002	1.72	48.70	0.25	1.00
1,1,1-TCA	133.4	126	0.00024	0.030	0.00106	1.72	48.70	0.25	1.21
1,1-DCA	98.96	30	0.00024	0.007	0.00026	1.72	48.70	0.25	1.05
Chlorobenzene	112.56	126	0.00024	0.030	0.00107	1.72	48.70	0.25	1.21
1,2-Dichlorobenzene	147	186	0.00024	0.045	0.00158	1.72	48.70	0.25	1.31
1,3-Dichlorobenzene	147	170	0.00024	0.041	0.00144	1.72	48.70	0.25	1.28
1,4-Dichlorobenzene	147	159	0.00024	0.038	0.00134	1.72	48.70	0.25	1.26
Benzene	84	79	0.00024	0.019	0.00067	1.72	48.70	0.25	1.13
Toluene	98	190	0.00024	0.046	0.00161	1.72	48.70	0.25	1.31
Ethylbenzene	112	468	0.00024	0.112	0.00397	1.72	48.70	0.25	1.77
Xylenes	112	394	0.00024	0.095	0.00334	1.72	48.70	0.25	1.65

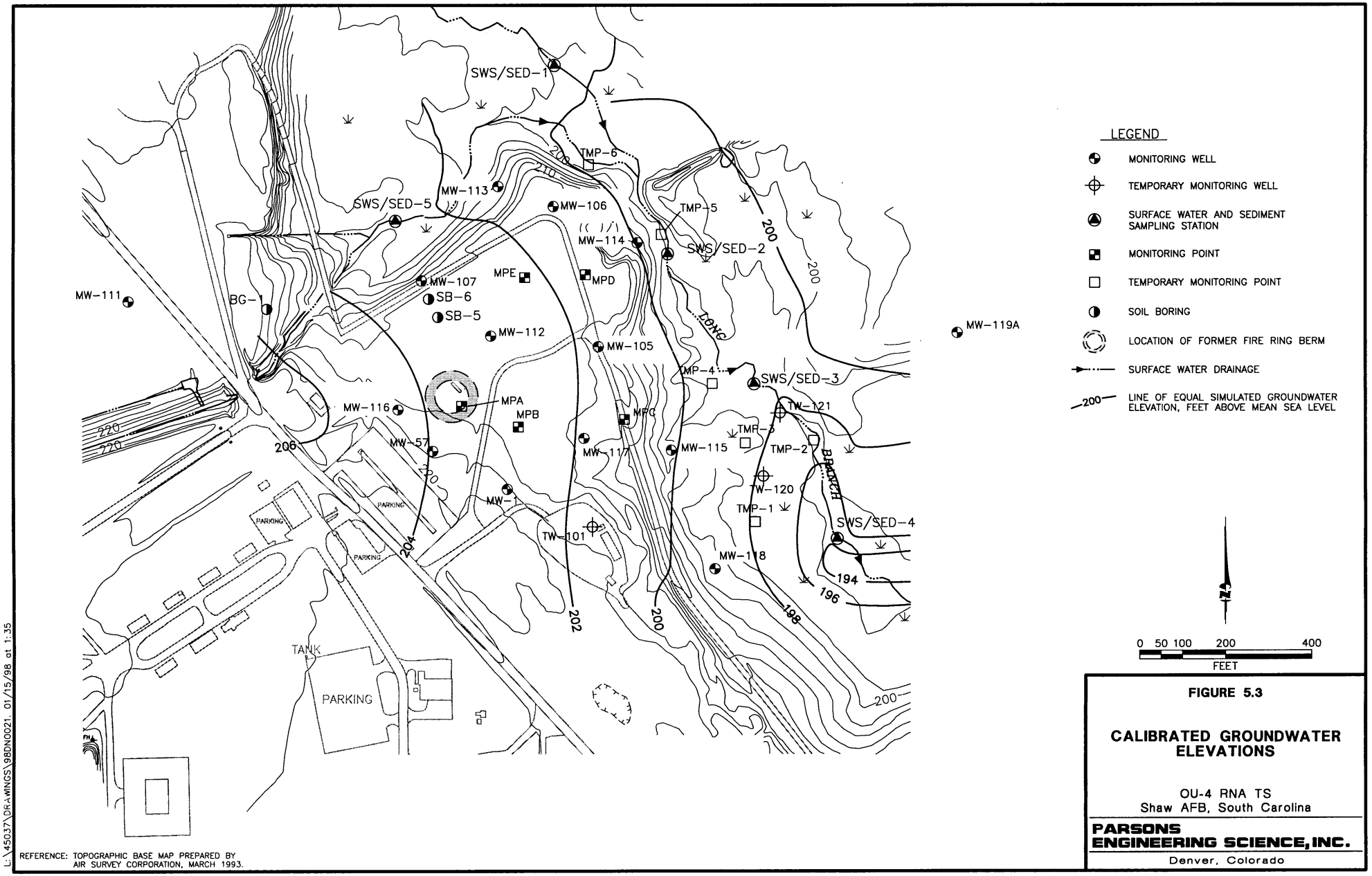
NOTES:

[a/] From technical protocol (Wiedemeier *et al.*, 1996), Knox *et al.* (1993), and Montgomery *et al.*, (1990).

[b/] FOC value measured from soil samples at the site (Rust, 1995).

[c/] Assumes an aquifer grain density of 2.65 (quartz sand) and a volumetric porosity of 35%.

[d/] An effective porosity of 0.25 was estimated in the RFI (Parsons ES, 1997).



LEGEND

- MONITORING WELL
- TEMPORARY MONITORING WELL
- SURFACE WATER AND SEDIMENT SAMPLING STATION
- MONITORING POINT
- TEMPORARY MONITORING POINT
- SOIL BORING
- LOCATION OF FORMER FIRE RING BERM
- SURFACE WATER DRAINAGE
- 200 — LINE OF EQUAL SIMULATED GROUNDWATER ELEVATION, FEET ABOVE MEAN SEA LEVEL

N

0 50 100 200 400
FEET

REFERENCE: TOPOGRAPHIC BASE MAP PREPARED BY AIR SURVEY CORPORATION, MARCH 1993.

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FIGURE 5.3

CALIBRATED GROUNDWATER ELEVATIONS

OU-4 RNA TS
Shaw AFB, South Carolina

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

$$RMS = \left[\frac{1}{n} \sum_{i=1}^{n} (h_m - h_s)_i^2 \right]^{0.5}$$

where: n = the number of points where heads are being compared,

h_m = measured head value, and

h_s = simulated head value.

The RMS error between observed and calibrated values at the 11 comparison points was 0.28 feet, which corresponds to a calibration error of 6.4 percent (water levels dropped approximately 4.51 feet over the portion of the model domain containing the monitoring wells/points listed above). In solving the groundwater flow equation, Visual MODFLOW establishes the water table surface and calculates an overall hydraulic balance that accounts for the numerical difference between flux into and out of the system. The hydraulic mass balance for the calibrated model was adequate to accomplish the objectives of this modeling effort, with a 0-percent discrepancy.

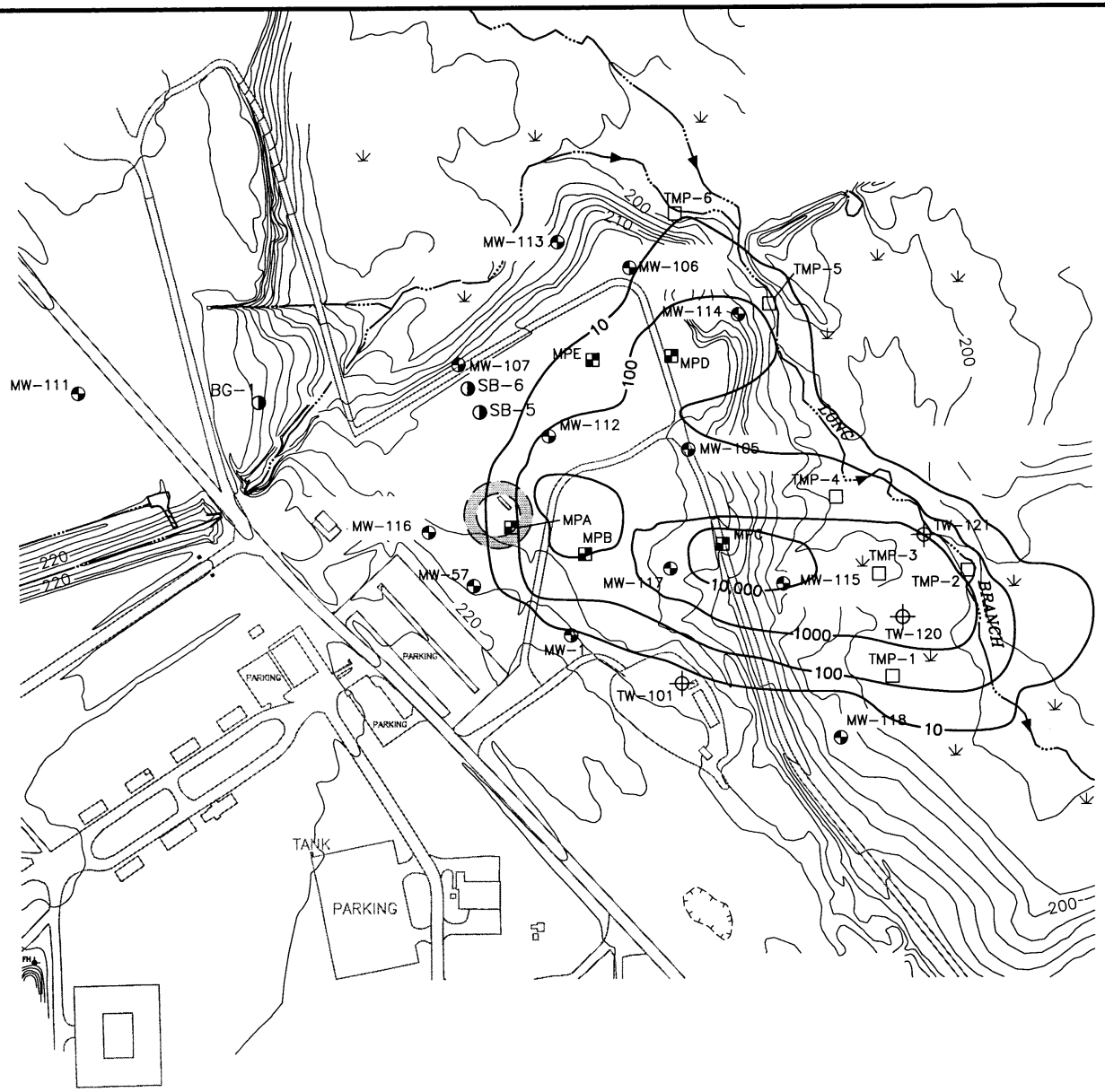
5.4.2 Plume Calibration

After calibration of the flow model, the numerical solute transport model was calibrated by altering the contaminant specified-flux rate in the source cells and contaminant transport parameters in a trial-and-error fashion until the simulated plume approximated observed field values. The transport parameters varied during plume calibration were the source concentrations and the plume dispersivity. Because the original estimates for these parameters resulted in a calculated plume that reasonably resembled the original plume, these parameters were not varied greatly.

The dissolved CAH concentrations obtained from April 1997 laboratory analytical data from 23 monitoring wells/points sampled by Parsons ES were used to calibrate the contaminant transport model. The calibration points were MW-105, MW-106, MW-107, MW-112, MW-113, MW-114, MW-115, MW-116, MW-117, MW-118, TW-101, TW-120, TW-121, MPA, MPB, MPC, MPD, MPE, TMP-1, TMP-2, TMP-3, TMP-4, and TMP-5.

The longitudinal dispersivity of 50 feet produced a reasonable simulated plume but was decreased to 10 feet in the source area because dispersivity is scale-dependent. This is the value used to produce the calibrated plume depicted on Figure 5.4.

The calibrated plume calculated by the model (Figure 5.4) is similar, but not identical, to the observed May 1997 plume (Figure 5.2). Simulated CAH concentrations in the three simulated source areas are slightly higher than observed March 1997 concentrations. The simulated total CAH concentration at temporary monitoring point MPC is 30,260 µg/L, whereas the concentrations observed at that well was 30,237 µg/L. CAH concentrations simulated at this location were the largest in the



LEGEND

- MONITORING WELL
- TEMPORARY MONITORING WELL
- MONITORING POINT
- TEMPORARY MONITORING POINT
- SOIL BORING
- LOCATION OF FORMER FIRE RING BERM
- SURFACE WATER DRAINAGE
- 100 LINE OF EQUAL SIMULATED TOTAL CAH CONCENTRATION (µg/L)

0 50 100 200 400
FEET

REFERENCE: TOPOGRAPHIC BASE MAP PREPARED BY AIR SURVEY CORPORATION, MARCH 1993.

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FIGURE 5.4

CALIBRATED TOTAL CAH PLUME

OU-4 RNA TS
Shaw AFB, South Carolina

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

model. Simulated CAH concentrations at the other two source areas were 57 µg/L (MPA within former fire training berm) and 307 µg/L (MPD where groundwater sheen detected) compared to actual concentrations of 48 and 288 µg/L, respectively. Simulated CAH concentrations at monitoring points adjacent to the creek varied. For instance, the measured CAH concentrations at TW-121 (edge of east/southeast plume lobe) and TMP-5 (downgradient edge of northeast plume lobe) were 424 µg/L and 75 µg/L versus observed concentrations of 57 and 164 µg/L, respectively. In general, simulated CAH concentrations at the plume toe exceeded observed concentrations.

Higher simulated concentrations in the source area indicate that an adequate amount of mass is being introduced to the modeled system. Higher simulated concentrations midway through the plume shows that the model conservatively accommodates more mass than there is reason to believe is present. Similarly, higher simulated groundwater concentrations near the edge of the creek probably will exceed actual groundwater concentrations. Therefore, the conservative features of the model by maintaining simulated groundwater concentrations above observed groundwater concentrations dictates that the model predicts the worst possible groundwater impacts at the site.

5.5 SENSITIVITY ANALYSIS

The purpose of the sensitivity analysis is to determine the effect of varying model input parameters on model output. The sensitivity analysis was conducted by varying hydraulic conductivity, the coefficient of retardation, the first-order decay rate, dispersivity, and the CAH injection rate.

To perform the sensitivity analyses, the calibrated model was adjusted by systematically changing the aforementioned parameters individually, and then comparing the new simulations to the results of the calibrated model. The models were run for a 2-year period, just as the calibrated model was, so that the independent effect of each variable could be assessed. Eight sensitivity runs of the calibrated model were made, with the following variations:

A. Hydraulic conductivity uniformly increased by a factor of 2;

B. Hydraulic conductivity uniformly decreased by a factor of 2;

C. Dispersivity uniformly increased by a factor of 2;

D. Dispersivity uniformly decreased by a factor of 2;

E. Coefficient of retardation uniformly increased by 50 percent;

F. Coefficient of retardation uniformly decreased by 50 percent;

G. First order decay rate increased by an order of magnitude; and

H. First order decay rate decreased by an order of magnitude.

The results of the sensitivity analyses are discussed in the following subsections and primarily address sensitivity variations in the east/southeast plume lobe, which has the highest total CAH concentrations at the site. As described in the following paragraphs, the parameter modifications listed above generally resulted in significant changes in the resulting plumes, with the retardation modifications having the smallest effect.

5.5.1 Sensitivity to Variations in Hydraulic Conductivity

Hydraulic conductivity is an important aquifer characteristic that represents the ability of the water-bearing strata to transmit groundwater. An accurate estimate of hydraulic conductivity is important to help quantify advective groundwater flow velocities and to define the flushing potential of the aquifer. As a result, models used to estimate contaminant transport are particularly sensitive to variations in hydraulic conductivity. Lower values of hydraulic conductivity result in a slower-moving plume. Higher values of hydraulic conductivity result in a faster-moving plume. The effects of varying hydraulic conductivity are summarized in Table 5.3. Uniformly increasing the hydraulic conductivity by a factor of two decreased the lateral dispersion of the plume to cause a slight shrinking in plume size. Simulated total CAH concentrations in the source areas decreased as simulated throughput through the source area was increased. For instance, concentrations at monitoring well MPC decreased from 30,261 µg/L to 18,102 µg/L with increased hydraulic conductivity. Simulated total CAH concentrations were observed to increase near Long Branch Creek due to higher transport velocities and decreased residence times for biodegradation. In contrast, decreasing the hydraulic conductivity by a factor of two slowed overall plume migration, and caused the contaminant mass to be concentrated within a smaller area. As a result, CAH levels in the vicinity of source areas increased (monitoring point MPC increased from 30,261 µg/L to 46,732 µg/L) and the simulated CAH concentrations near Long Branch Creek uniformly decreased (monitoring wells OBS-A and TMP-5 decreased by approximately 1,215 and 37 µg/L, respectively).

5.5.2 Sensitivity to Variations in Dispersivity

The effects of varying dispersivity are summarized in Table 5.3. Both longitudinal and transverse dispersivity were varied for this analysis, as the ratio of the two values was kept constant at 0.1. Increasing the dispersivity by a factor of two resulted in relatively lower concentrations in the source area. The simulated concentration at source area monitoring point locations MPC was 27,999 µg/L, compared to a calibrated concentration of 30,261 µg/L. Corresponding decreases were observed downgradient from the source area, causing the simulated concentration at well OBS-A to decrease from 2,103 µg/L in the calibrated model to 1,929 µg/L.

Decreasing the dispersivity by a factor of two produced a plume with slightly higher concentrations in the source area. The simulated concentration at monitoring point MPC was 31,538 µg/L, compared to the calibrated model concentration of 30,261 µg/L. The CAH concentrations in the downgradient portion of the plume also were higher. The simulated concentration at observation well OBS-A was 2,208 µg/L, compared to the observed concentration of 2,103 µg/L at that well.

TABLE 5.3
SENSITIVITY ANALYSIS RESULTS
OU4 RNA TS
SHAW AFB, SOUTH CAROLINA

Well No.	Measured Total CAH Plume Concentration May '97 (μg/L)[a/]	Calibrated Total CAH Plume Concentration (μg/L)	K x2[b/]	K/2	α x 2[c/]	α / 2	Retardation Increased by 50%	Retardation Decreased by 50%	Decay Rate by by 10	Decay Rate Decreased by 10
East/Southeast Plume Lobe										
MPA	48	57	36	77	150	18	57	58	7054	89
MPB	444	463	319	567	524	451	455	466	28	825
MPC	30237	30261	18012	4673	2799	31538	30169	30473	10577	39310
MW-117	6088	6856	4267	9958	7528	6390	6812	6906	1851	9862
MW-115	13149	13321	10545	13238	12366	13872	13093	13521	422	29687
OBS-A	1629[d/]	2103	2752	888	1929	2208	2010	2172	0	11812
Northeast Plume Lobe										
MPD	288	304	15	416	305	301	301	307	55	571
MW-114	148	169	164	129	164	171	165	173	2	593
TMP-5	164	75	82	38	78	73	72	78	0	391

a/ μg/L = micrograms per liter.

b/ K = hydraulic conductivity.

c/ α = dispersivity.

d/ The measured value for monitoring point TMP-2 was used for observation well OBS-A.

Note: The adjustments made to the calibrated model during the various sensivity analysis runs are more fully described in Section 5.5.

5.5.3 Sensitivity to Variations in the Coefficient of Retardation

The effects of varying the coefficient of retardation are summarized in Table 5.3. Uniformly increasing the coefficient of retardation by 50 percent slightly limited the downgradient migration of the plume. The simulated total CAH molar concentration in the vicinity of source area monitoring point MPC was 30,169 µg/L, compared to the calibrated concentration of 30,261 µg/L. A small decrease in the downgradient concentrations of the total CAH plume occurred, as evidenced by a simulated CAH concentration of 2,010 µg/L at observation well OBS-A, where the calibrated CAH concentration was 2,103 µg/L. In contrast, decreasing the coefficient of retardation by 50 percent slightly increased plume migration. As a result, the simulated CAH concentration at source area monitoring point MPC increased by approximately 200 µg/L as source areas upgradient from MPC released more contaminant mass downgradient. Concentrations downgradient from the source area also increased (CAH concentrations changed from 2,103 to 2,172 µg/L at observation well OBS-A). Overall, varying the coefficient of retardation within a reasonable range has a limited effect on contaminant transport.

5.5.4 Sensitivity to Variations in the Anaerobic Decay Rate Constant

The effects of varying the first-order CAH decay rate are summarized in Table 5.3. Increasing this parameter by an order of magnitude results in more rapid degradation of dissolved contaminants. The resulting simulated CAH concentrations at source area well MPC and at downgradient observation well OBS-A were lower than in the calibrated model (10,577 µg/L and 0 µg/L, respectively). Increasing the degradation rate by an order of magnitude results in a much smaller plume. In contrast, decreasing this parameter by an order of magnitude causes a large increase in CAH concentrations throughout the entire plume. For instance, groundwater CAH concentrations at monitoring point MPC and observation well OBS-A increased to 39,310 and 11,812 µg/L, respectively.

5.5.6 Summary of Sensitivity Analysis Results

The results of the sensitivity analysis suggest that the calibrated model depicted in Figure 5.4 is reasonable. Varying the model parameters within the prescribed ranges generally caused the extent and magnitude of the dissolved plume to differ substantially from observed site conditions.

SECTION 6

COMPARATIVE ANALYSIS OF REMEDIAL ALTERNATIVES

This section presents the development and comparative analysis of two groundwater remedial alternatives for OU-4 at Shaw AFB. The intent of this evaluation is to determine if RNA is an appropriate and cost-effective remedial approach to consider when developing final remedial strategies for the CAHs dissolved in site groundwater, especially when combined with other innovative and conventional remedial technologies. A groundwater extraction and treatment system consisting of at least two extraction wells will be installed as an interim measure (IM) during the spring of 1998 near wells MW-117 and MW-112. The intent of this system is to mitigate contaminant plume migration until the option of monitored natural attenuation is evaluated, largely through the results of this TS. The predicted effects of an interim, limited-term (two year) groundwater extraction and treatment system, combined with natural attenuation, are described in this section. The modeling effort did not include predictions to determine the future extent and concentration of the BTEX plume at OU-4 due to lower BTEX concentrations relative to CAH concentrations, the role of BTEX as electron donors for CAH degradation, and the fact that detectable concentrations of BTEX are not present in surface water.

Section 6.1 presents the criteria used to evaluate groundwater remedial alternatives. Section 6.2 discusses the development of remedial alternatives considered as part of this demonstration project. Section 6.3 provides a brief description of each of these remedial alternatives. Section 6.4 provides a more detailed analysis, including modeling results, of the remedial alternatives using the defined evaluation criteria. The results of this evaluation process are summarized in Section 6.5.

6.1 REMEDIAL ALTERNATIVE EVALUATION CRITERIA

The evaluation criteria used to identify appropriate remedial alternatives for shallow groundwater contamination at the site were adapted from those recommended by USEPA (1988) for selecting remedies for Superfund sites (OSWER Directive 9355.3-01). These criteria include (1) long-term effectiveness and permanence, (2) technical and administrative implementability, and (3) relative cost. The following sections briefly describe the scope and purpose of each evaluation criterion. This report focuses on the potential use of RNA to reduce CAH concentrations within the shallow groundwater to levels that meet regulatory standards intended to be protective of human health and the environment.

6.1.1 Long-Term Effectiveness and Permanence

Each remedial approach or remedial alternative (which can be a combination of remedial approaches such as RNA and institutional controls) was analyzed to determine how effectively it will minimize groundwater plume expansion so that applicable groundwater quality standards can be achieved at a downgradient POC. The expected remedial effectiveness based on case histories from other sites with similar conditions also is evaluated where feasible. The ability to minimize potential impacts on surrounding areas, facilities, and operations is considered. Also, the ability of each remedial alternative to protect both current and potential future receptors from potential exposures associated with site-related contamination in shallow groundwater is qualitatively assessed by conservatively evaluating the potential for completion of exposure pathways involving groundwater, either now or in the future. This evaluation criterion also includes permanence and the ability to reduce contaminant mass, toxicity, and volume. Time to implementation and estimated time until protection is achieved are described. Long-term reliability for providing continued protection, including an assessment of potential for failure of the technology and the potential threats resulting from such a failure, also is evaluated.

6.1.2 Implementability

The technical implementation of each remedial technology/approach or remedial alternative was evaluated in terms of technical feasibility and availability. Potential logistical shortcomings and difficulties in construction, operations, and monitoring are presented and weighed against perceived benefits. Requirements for any post-implementation site controls such as LTM and land or groundwater use restrictions are described. Administrative feasibility in terms of public acceptance and the ability to obtain necessary approvals is discussed.

6.1.3 Cost

The total cost (present worth) of each remedial alternative was estimated for relative comparison following USEPA (1993) guidance. An estimate of capital costs, and operations and post-implementation costs for site monitoring and controls is included. An annual adjustment (discount) factor of 7 percent was assumed in present-worth calculations (USEPA, 1993).

6.2 FACTORS INFLUENCING ALTERNATIVES DEVELOPMENT

Several factors were considered during the identification and screening of remedial technologies for addressing shallow groundwater contamination at the site. Factors considered included the objectives of the natural attenuation demonstration program; contaminant, groundwater, and soil properties; present and future land uses; and potential receptor exposure pathways. The following section briefly describes each of these factors and how they were used to narrow the list of potentially applicable remedial technologies to the final remedial alternatives considered for the site.

6.2.1 Program Objectives

The intent of the RNA demonstration program sponsored by AFCEE is to develop a systematic process for scientifically investigating and documenting naturally occurring subsurface attenuation processes that can be factored into overall site remediation plans. The objective of this program is to provide solid evidence of RNA of dissolved CAHs so that this information can be used to develop an effective groundwater remediation strategy. A secondary goal of this multi-site initiative is to provide a series of regional case studies that demonstrate that natural processes of contaminant degradation can often reduce contaminant concentrations in groundwater to below acceptable cleanup standards before completion of potential exposure pathways.

Because the objective of this program is to study natural processes in the saturated zone rather than all contaminated media (vadose zone soil, soil gas, etc.), remedial approaches and technologies have been evaluated based primarily on their potential impact on shallow groundwater and phreatic soils. Technologies that can reduce vadose zone contamination and partitioning of contaminants into groundwater also have been evaluated. Many of the source removal technologies evaluated in this section also will reduce soil and soil gas contamination, but it is important to emphasize that the remedial alternatives developed in this document are not necessarily intended to remediate all contaminated media.

Additional program objectives set forth by AFCEE include cost effectiveness and minimization of waste. Approaches and technologies that may meet these criteria include institutional controls, soil vapor extraction, air sparging, and RNA. Soil excavation, slurry walls, sheet piling, carbon adsorption, *ex situ* biological or chemical treatment, groundwater pump and treat, and onsite/offsite disposal generally are not attractive technology candidates under this program.

6.2.2 Contaminant Properties

The site-related chlorinated solvent contaminants evaluated as part of this TS include 1,1,1-TCA, 1,1-DCA, PCE, TCE, *cis*- and *trans*-1,2-DCE, 1,1-DCE, VC, DCB, and CB. Three contaminant sources areas have been identified; sources include LNAPL floating on the water table and/or residual contamination adsorbed to soils. Two of the source areas contribute relatively little to groundwater CAH contamination, whereas the third source area appears to cause concentrated CAH contamination in the east/southeast plume lobe (Section 4). The physiochemical characteristics of the individual CAH compounds within these plumes will greatly influence the effectiveness and selection of a remedial technology.

Several of the chlorinated solvents present at OU-4 were not evaluated in the selection of remedial alternatives for the site. The compounds DCB and CB were present below USEPA MCLs and were omitted from this evaluation. The remaining chlorinated solvents detected in site groundwater include 1,1,1-TCA, 1,1-DCA, 1,2-DCA, PCE, TCE, *cis*- and *trans*-1,2-DCE, 1,1-DCE, and VC. Most of these compounds were detected at relatively low concentrations and/or were detected at a single monitoring well/point location (e.g., *trans*-1,2-DCE and 1,2-DCA), and are not considered a primary groundwater threat. The compounds 1,1,1-TCA, *cis*-1,2-DCE,

and 1,1-DCA represent approximately 94 percent of the groundwater CAH plume mass.

1,1,1-TCA was used as the target remediation compound at OU-4. The summary of biodegradation rates in Table 4.9 indicates that the transformation rates of 1,1,1-TCA to daughter products (1,1,1-TCA comprises approximately 70 percent of all dissolved chlorinated ethane mass) versus the transformation rates of *cis*-1,2-DCE to VC (*cis*-1,2-DCE also comprises approximately 70 percent of all dissolved chlorinated ethene mass) were nearly identical. However, the maximum *cis*-1,2-DCE concentration was detected at the same location as the maximum 1,1,1-TCA concentration, but at a concentration approximately five times lower than 1,1,1-TCA. The relatively high 1,1,1-TCA concentrations support the use of this compound as a surrogate for all CAH compounds at this site during the remedial alternatives evaluation process. The selection of 1,1,1-TCA in this evaluation also is consistent with the selection of 1,1,1-TCA as the target remedial compound for interim measures being conducted at the site by IT Corporation (SCDHEC, 1997).

All of the CAHs detected at OU-4 are generally volatile, relatively soluble in water, and do not adsorb strongly to soil particles. These characteristics allow the CAHs to leach readily from DNAPL and contaminated soil into groundwater, and to migrate as dissolved contamination (Lyman *et al.*, 1992). Many CAHs are susceptible to *in situ* degradation by both biotic and abiotic mechanisms under certain geochemical conditions.

1,1,1-TCA, the selected surrogate compound, is a volatile compound with a vapor pressure of 124 millimeters of mercury (mm Hg) at 25°C (Neely and Blau, 1985). Henry's Law Constants reported for 1,1,1-TCA range from 0.013 to 0.023 atmosphere-cubic meters per mole (atm-m^3/mol) at 25°C (Ashworth *et al.*, 1988; Dewulf *et al.*, 1995; Hine and Mookerjee, 1975; and Hunter-Smith *et al.*, 1983). The solubility of pure 1,1,1-TCA in water at 25°C has been reported to range from 347 to 1,334 mg/L (Howard, 1990; Neely and Blau, 1985). 1,1,1-TCA biodegradation products vary according to the prevailing groundwater geochemistry, and are described in Section 4.2.

On the basis of these physiochemical characteristics, natural attenuation, soil vapor extraction, air sparging, groundwater extraction, and air stripping technologies could all be effective options for collecting, destroying, and/or treating CAHs at OU-4. In addition, *in situ* degradation of CAHs via permeable reaction walls (e.g., iron filings trenches) is a developing technology that holds promise for treatment of CAHs dissolved in groundwater.

6.2.3 Site-Specific Conditions

Two general categories of site-specific characteristics were considered when identifying remedial technologies for comparative evaluation as part of this demonstration project. The first category included physical characteristics such as groundwater depth, gradient, flow direction, and soil type, which influence the types of remedial technologies most appropriate for the site. The second category involved assumptions about future land uses and potential receptor exposure pathways. Each of

these site-specific characteristics have influenced the selection of remedial alternatives included in the comparative evaluation.

6.2.3.1 Groundwater and Soil Characteristics

Site geology and hydrogeology will have a profound effect on the transport of contaminants and the effectiveness and scope of required remedial technologies at a given site. Hydraulic conductivity is perhaps the most important aquifer parameter governing groundwater flow and contaminant transport in the subsurface. The velocity of the groundwater and dissolved contamination is directly related to the hydraulic conductivity of the saturated zone. Slug tests conducted in OU-4 indicate a moderate to high conductivity within the Duplin Formation terrace deposits, which primarily consist of unconsolidated, well- to poorly-graded sands. Estimated conductivity values for these deposits ranged from 18 ft/day (based on a pump test) to 81 ft/day (based on slug tests). The shallow groundwater migrates to the northeast, east, and southeast, increasing the extent of contamination from the source area to Long Branch Creek (i.e., the plume has expanded). However, the CAH concentrations have decreased within the aquifer with distance from the source areas through dilution and biodegradation. Groundwater migration from the source areas to Long Branch Creek takes two years given the estimated groundwater velocities at OU-4 (Section 3). The combination of rapid groundwater velocities and discontinued fire training operations in 1969 indicate that steady-state or shrinking plume conditions currently are achieved at OU-4.

Although higher hydraulic conductivities have resulted in plume expansion and migration toward the bounding creek, this same characteristic also will enhance the effectiveness of remedial technologies such as groundwater and soil vapor extraction and air sparging. For example, it should be less expensive and time-consuming to capture and treat the contaminant plume using a network of extraction wells in the highly conductive soils. Contaminant recovery also may be maximized when contaminants are not significantly sorbed to and retarded by phreatic soil, as in the predominantly sandy soils at the site. The effectiveness of air sparging also may be increased in highly conductive aquifers because of reduced entry pressures and increased radius of influence. Greater hydraulic conductivity also would increase the amount of contaminant mass traveling through an air sparging network within a given time period.

To satisfy the requirements of 1,1,1-TCA biodegradation, the aquifer must provide an adequate and available carbon or energy source, relatively reducing conditions, suitably low concentrations of competing electron acceptors (e.g., DO), and proper ranges of pH and temperature. Data collected as part of the field work phase of this demonstration project (Sections 3 and 4) indicate that these conditions are present in the source areas of the groundwater plume; thereby contributing to the degradation of highly chlorinated CAHs through reductive dechlorination and additional abiotic degradation of 1,1,1-TCA through dehydrohalogenation. Indigenous microorganisms capable of degrading CAHs tend to be common in most soil environments, and appear to be active at OU-4. Indigenous microorganisms have a distinct advantage over microorganisms injected into the subsurface to enhance biodegradation because indigenous microorganisms are well adapted to the physical and chemical conditions of the subsurface in which they reside (Goldstein *et al.*, 1985). Therefore, microbe addition is not considered a viable remedial technology for this site.

6.2.3.2 Potential Exposure Pathways

A pathways analysis identifies the human and ecological receptors that could potentially come into contact with site-related contamination and the contaminant migration pathways through which these receptors might be exposed. To have a completed exposure pathway, there must be a source of contamination, mechanism(s) of release, a pathway of transport to an exposure point, an exposure point, and a receptor. If any of these elements do not exist, the exposure pathway is considered incomplete, and receptors will not come into contact with site-related contamination. Evaluation of the potential long-term effectiveness of any remedial technology or remedial alternative as part of this demonstration project includes determining if the approach will be sufficient and adequate to minimize plume expansion so that potential receptor exposure pathways involving shallow groundwater contaminants are incomplete.

Assumptions about current and future land uses at a site form the basis for identifying potential receptors, exposure pathways, reasonable exposure scenarios, and appropriate remediation goals. USEPA (1988) advises that the land use associated with the highest (most conservative) potential level of exposure and risk that can reasonably be expected to occur should be used to guide the identification of potential exposure pathways and to determine the level to which the site must be remediated.

Most of OU-4 is a grassland/shrub habitat generally devoid of large vegetation. The site becomes more heavily vegetated with bottomland forest adjacent to Long Branch Creek. The former fire-training berm itself lacks any vegetation. The site is undeveloped with the exception of a picnic area located approximately 200 feet west of the former fire training berm. Therefore, the primary use of OU-4 is for recreational activities, and it is estimated that the picnic area is used 2 to 3 times per month during the spring to early fall months (Rust E&I, 1995).

Rural/residential land begins within 1,000 feet north and east of OU-4 and primarily is used for agricultural purposes. The areas south and west of the site are occupied by Base facilities. A Munitions Flight unit is located approximately 350 feet southwest of the site and a equipment storage area is located approximately 400 feet southeast. The water from Long Branch Creek discharges to a privately owned pond called Booths Pond, located approximately 1,000 feet south/southeast from the site. Groundwater sampling results indicate that the CAH plume may currently be impacting water quality in Long Branch Creek. However, as expressed in the baseline risk assessment (BRA) (Rust E&I, 1995), contaminants from other sources along Long Branch Creek also could be transported to Booths Pond and the pond was, therefore, not considered in the BRA.

Under reasonable current land use assumptions, potential receptors include Base worker populations, Base residents, residents living southeast of the Base, trespassers who enter the site, and recreators in Booths Pond or Long Branch Creek. The nearest employees to the site on a daily basis work at the Munitions Flight Unit. However, Munitions Flight Unit personnel do not come into direct contact with the site on a daily basis, although they utilize the parking area adjacent to the site. Potential contact with site contaminants could come from adults and children wading in Long Branch Creek while hunting, fishing, or playing. The ingestion of fish caught from the creek or Booths Pond would be another potential exposure route. According to Rust (1995),

there are no potable water supply wells at OU-4. The nearest supply wells (Base Wells 8 and 10) are located in the Munitions Flight Unit area and have been abandoned. Exposure pathways involving other environmental media such as vadose zone soils and soil gas in the source area were not considered as part of this project, but should be considered in overall site remediation decisions.

Assumptions about hypothetical future land uses also must be made to ensure that the remedial technology or alternative considered for shallow groundwater at the site is adequate and sufficient to provide long-term protection. The future use of OU-4 and the surrounding area is projected to be unchanged from the current uses described above. However, the possibility of Shaw AFB closing in the future exists, and land use could change. As part of the BRA (Rust E&I, 1995), future land use has conservatively been assumed to include on-site residential. Future receptor exposure to groundwater could occur through the use of an on-site well screened in the shallow aquifer and subsequent groundwater ingestion, dermal absorption while bathing, or inhalation of vapors during showering. Exposure to contaminants in a residential exposure scenario also could arise through absorption and ingestion during recreational contact with surface waters of Long Branch Creek or Booths Pond.

In summary, the use of RNA at this site will require that the source area be maintained as industrial or open-space (undeveloped) property and that restrictions on shallow groundwater use be enforced in areas downgradient from the site until natural attenuation reduces contaminants to concentrations that meet regulatory standards. Although shallow groundwater is in hydraulic communication with Long Branch Creek, contaminant concentrations detected in surface water were low (maximum CAH concentration was 2.3 µg/L *cis*-1,2-DCE at SWS-3). The substantial estimated flow volume of Long Branch Creek [>1,000 gallons per minute (gpm) (Rust E&I, 1995)], aerobic degradation processes, photooxidation, and volatilization are expected to dilute and degrade any CAH compounds entering the creek. If source removal technologies such as soil vapor extraction or groundwater pump and treat are implemented, they will have some impact on the short- and long-term land use options and also will require some level of institutional control and worker protection during remediation.

6.2.3.3 Remediation Goals for Shallow Groundwater

Potentially applicable state and federal water quality criteria for 1,1,1-TCA are summarized in Table 6.1.

Use of RNA assumes that compliance with promulgated drinking water standards is not necessary if site-related contamination does not pose an immediate threat to human health or the environment (i.e., exposure pathways are incomplete). Thus, the magnitude of required remediation in areas that can and will be placed under institutional control is different from the remediation that is required in areas that may be available for unrestricted groundwater use. The primary remedial action objective (RAO) for groundwater at and downgradient from OU-4 is limited plume expansion to prevent exposure of site receptors to concentrations of CAHs in groundwater and surface water at levels that exceed regulatory standards or guidelines. This means that viable remedial alternatives must be able to achieve concentrations that minimize plume migration and/or expansion. Institutional controls are likely to be a necessary component of any groundwater remediation strategy for this site. The required

TABLE 6.1
REMEDIAL ACTION OBJECTIVES FOR GROUNDWATER AND SURFACE WATER
OU-4 RNA TS
SHAW AFB, SOUTH CAROLINA

Compound	USEPA MCL[a/] (µg/L)[b/]	Interim Measure Remedial Goal[c/] (µg/L)	Federal Ambient Surface Water Quality, Ingestion of Organisms [d/] (µg/L)
1,1,1-Trichloroethane	200	1,000	170,000

[a/] USEPA MCL = US Environmental Protection Agency (1996) Maximum Contaminant Level.
[b/] µg/L = micrograms per liter.
[c/] South Carolina Department of Health and Environmental Control (SCDHEC, 1997).
[d/] USEPA (1991). Note: This standard relates to the possible ingestion of aquatic organisms in Long Branch Creek.

duration of these institutional controls may vary depending on the effectiveness of the selected remedial technology at reducing contaminant mass and concentration in the groundwater, and the amount of contaminated groundwater discharging to surface water.

6.2.4 Summary of Remedial Technology Screening

Several remedial technologies were identified and screened for use in treating the groundwater at the site. Table 6.2 identifies the initial remedial technologies considered as part of this demonstration and those retained for detailed comparative analysis. Screening was conducted systematically by considering the program objectives of the AFCEE RNA demonstration, physiochemical properties of the CAH compounds, and other site-specific characteristics such as hydrogeology, land use assumptions, potential exposure pathways, and appropriate remediation goals. All of these factors will influence the technical effectiveness, implementation, and relative cost of technologies for remediating shallow groundwater underlying and migrating from the site. The remedial approaches and source removal technologies retained for development of remedial alternatives and comparative analysis include institutional controls, RNA combined with LTM, and soil vapor extraction (SVE) with potential aboveground treatment of extracted vapor. Groundwater extraction and treatment was not retained because it does not fulfill AFCEE's program objectives for waste minimization. However, the planned, limited groundwater extraction and treatment system to be installed during the spring/summer of 1998 by IT was considered in the implementation of remedial alternatives.

TABLE 6.2
INITIAL TECHNICAL IMPLEMENTABILITY SCREENING OF TECHNOLOGIES AND PROCESS OPTIONS FOR GROUNDWATER REMEDIATION
OU-4 RNA TS
SHAW AFB, SOUTH CAROLINA

General Response Action	Technology Type	Process Option	Implementability	Effectiveness	Relative Cost	Retain
Long-Term Monitoring	Periodic Groundwater / Surface Water Monitoring	Confirmation Wells	New monitoring wells must be installed along the centerline of the plume lobes to properly characterize the progress of remediation. Sufficient space exists for additional wells.	Necessary for all remedia-tion strategies	Low	Yes
		Sentry Wells	The probable point-of-compliance likely has been impacted. The point-of-compliance (i.e., Long Branch Creek) will need to be monitored to confirm the progress of remediation.	Necessary	Low	No
		Surface Water	As stated above, surface water of Long Branch Creek will be monitored.	Necessary	Low	Yes
Institutional Controls	Groundwater Use Control	Land Use Control/Regulate Well Permits	The plume lies within the Base boundary, and land and groundwater use are under Base jurisdiction.	Necessary	Low	Yes
		Seal/Abandon Existing Wells	No production wells are known to exist in the current or predicted plume area.	Not required at this site	Low	No
		Point-of-Use Treatment	No shallow groundwater is extracted from the plume area for any use.	Not required at this site	Moderate	No
	Public Education	Meetings/ Newsletters	Base public relations and environmental management offices have many information avenues through which to communicate to workers and residents.	Necessary	Low	Yes
Containment of Plume	Hydraulic Controls	Interceptor Trench Collection	Surface water has been impacted by discharge of contaminated groundwater. Marsh terrain near creek may inhibit the proper installation of a trench. No likely human receptors downgradient.	Low	Moderate	No
		Groundwater Extraction	No likely receptors downgradient from site and dissolved plume is projected to recede. Long-term groundwater extraction does not comply with program objectives; however, short-term groundwater extraction is currently proposed by the Base as an interim measure (IM) within the source area until the viability of natural attenuation can be assessed.	Moderate	Moderate	No
	Physical Controls	Slurry Walls/Grout Curtains	Limited effectiveness. Contaminated groundwater would seek alternate paths over, under, or around the walls enroute to the creek.	Low	High	No
		Sheet Piling	Limited effectiveness. Contaminated groundwater would seek alternate paths over, under, or around the walls enroute to the creek.	Low	High	No

TABLE 6.2 (continued)
INITIAL TECHNICAL IMPLEMENTABILITY SCREENING OF
TECHNOLOGIES AND PROCESS OPTIONS FOR GROUNDWATER REMEDIATION
OU-4 RNA TS
SHAW AFB, SOUTH CAROLINA

General Response Action	Technology Type	Process Option	Implementability	Effectiveness	Relative Cost	Retain
In Situ Groundwater Treatment	Reactive/ Semi-Permeable Barriers	Biologically Active Zones/Iron Filings Trench	Degradation of CAHs may be stimulated by allowing groundwater to flow through a nutrient-rich zone or zero-valent iron. New, unproven technologies.	Moderate	Moderate	No
	Biological	Oxygen and/or Nutrient Enhanced Biodegradation (Biosparging)	Nutrients and/or oxygen are injected within and/or downgradient of plume to limit plume migration by enhancing biodegradation and reducing CAH concentrations. Will inhibit anaerobic degradation of CAHs by oxygenating the groundwater. 1,1,1-TCA not aerobically biodegradable. Would be most effective downgradient of the source area. Not proven to be more effective than natural attenuation.	Low	Low	No
	Chemical/ Physical	Natural Attenuation	A combination of natural biological, chemical, and physical removal mechanisms which occur to varying degrees on every site. Groundwater sampling at OU-4 indicates that this is an ongoing remediation process.	High	Low	Yes
		Air Sparging (Volatilization)	Injection of air into contaminated aquifer creating a mass transfer of CAHs, specifically 1,1,1-TCA, into air bubbles and vadose zone. Similar to biosparging in effectiveness; however, more mass is transferred rather than destroyed. Most effectively used downgradient of the source so as not to upset anaerobic conditions promoting reductive dechlorination in the source area.	Low	Low	No
Source Removal/ Groundwater Remediation	Groundwater Extraction	Vertical Pumping Wells	Source area of groundwater plume is pumped by installing submersible pumps in source area wells. Produces a large volume of water which requires additional treatment. However, will rapidly stop the migration of 1,1,1-TCA toward Long Branch Creek if sufficient pumping rates can be sustained (>20 gallons per minute) in the source area. Does not comply with program objectives.	Moderate	Moderate	No
Aboveground Groundwater Treatment	Biological	Bioreactors	High flow rates require excessive retention times and large reactors. CAHs are often volatilized in these systems.	Moderate	High	No
	Chemical/ Physical	Air Stripping	Cost-effective technology for removing CAHs from groundwater at high flow rates. Potential permitting for air emissions.	High	Moderate	No
		Activated Carbon	Cost prohibitive for more concentrated CAHs. Creates a carbon disposal problem.	Moderate	High (O&M)	No

TABLE 6.2 (Continued)
INITIAL TECHNICAL IMPLEMENTABILITY SCREENING OF TECHNOLOGIES AND PROCESS OPTIONS FOR GROUNDWATER REMEDIATION
OU-4 RNA TS
SHAW AFB, SOUTH CAROLINA

General Response Action	Technology Type	Process Option	Implementability	Effectiveness	Relative Cost	Retain
Aboveground Groundwater Treatment		Direct Discharge to Industrial Waste Water Treatment Plant (IWWTP)	Implementable option only when an IWWTP is readily available and capable of handling contaminant and hydraulic loading. IWWTP not available for this site.	High	Low	No
		UV/Ozone Reactors	High flow rates require lengthy retention times and large, costly reactors.	Moderate	High	No
Treated Groundwater Disposal	Discharge to IWWTP or Sanitary Sewer	IWWTP	Implementable option only when an IWWTP is available and capable of handling hydraulic loading. IWWTP is not available.	High	Low	No
		Sanitary Sewer	Implementable option only when access to a sanitary sewer exists and hydraulic loading is acceptable.	High	Low	No
	Treated Groundwater Reinjection	Vertical Injection Wells	Injection wells subject to clogging, high maintenance, and permitting.	Moderate	Moderate	No
		Injection Trenches	Requires large trenches and can be subject to injection well permitting.	Moderate	Moderate	No
	Discharge to Surface Waters	Storm Drains	Generally requires NPDES or other discharge permit.	High	Low	No
Source Removal/Soil Remediation	Excavation/ Treatment	Landfilling	Some excavation may economically be feasible if it can be shown that source area is generally less than 2,000 cubic yards. For reasons of risk and cost reduction, in-situ methods preferable when possible.	Moderate to High	Moderate	No
		Biological Landfarming	Some excavation may be feasible at this site. For reasons of risk and cost reduction, *in-situ* methods preferable when possible.	Moderate to High	Moderate	No
		Thermal Desorption	Some excavation may be feasible at this site. For reasons of risk and cost reduction, *in-situ* methods preferable when possible.	Moderate to High	High	No
	In Situ	Bioventing	Air injection/extraction to increase soil oxygen levels and stimulate biodegradation of fuel residuals. Conductivity of site soils to air movement would be greater than to water movement. Might stimulate cometabolism of CAHs during the biodegradation of fuel contamination.	Moderate to High	Low	No
		Soil Vapor Extraction	Air extraction to increase soil oxygen levels and extract VOCs from vadose zone. Conductivity of site soils to air movement would be greater than to water movement. May be subject to air emissions permitting.	High	Low to Moderate	Yes

TABLE 6.2 (Concluded)
INITIAL TECHNICAL IMPLEMENTABILITY SCREENING OF TECHNOLOGIES AND PROCESS OPTIONS FOR GROUNDWATER REMEDIATION
OU-4 RNA TS
SHAW AFB, SOUTH CAROLINA

General Response Action	Technology Type	Process Option	Implementability	Effectiveness	Relative Cost	Retain
Source Removal/Soil Remediation (continued)	*In-Situ* (continued)	Soil Washing	Water and/or surfactant solution are forced through zones of residual contamination to enhance contaminant partitioning into the groundwater. Most effective in homogeneous sandy soils as present at OU-4.	Low	High	No
	Mobile LNAPL Recovery	Dual-Pump Systems	Best suited for sites with >1 foot mobile LNAPL. Sandy soils at OU-4 will enhance effectiveness. Current LNAPL thicknesses observed to be < 1 foot.	Moderate	High	No
		Skimmer Pumps, Bailers, Wicks	Best suited for sites with >1 foot mobile LNAPL. Sandy soils at OU-4 will enhance effectiveness. Current LNAPL thicknesses observed to be < 1 foot.	Moderate	Low to Moderate	No
		Total Fluids Pumping	Best suited for sites with thin saturated zones where excessive groundwater will not be pumped.	Moderate	High	No
		Vacuum-enhanced extraction	Best suited for low-permeability/low-transmissivity sites. Residual and mobile LNAPL, soil vapor, and groundwater can be extracted. Bioslurping is a subset of this technology.	Moderate to High	Moderate to High	No

Plume capture downgradient from the source area and prior to discharge to Long Branch Creek also could be accomplished by installing an air sparging curtain or iron filings trench (permeable reaction wall). An iron filings trench was installed below the upper terrace near Long Branch Creek in November 1998 to mitigate discharge of dissolved contaminants to the creek (see Appendix E for location). With an iron filings trench, groundwater contaminated with CAHs flows through granular, zero-valent iron filings placed in a trench, which is excavated perpendicular to the axis of groundwater flow. Dissolved CAHs are degraded through a series of less-chlorinated intermediates to non-toxic, non-chlorinated end products. However, iron filings trenches are a new, relatively unproven technology. The cost for the iron filings backfill can range from $400 to $450 per ton (Focht *et al.*, 1996) (approximately $740 to $840 per cubic yard), and the effective lifetime of an iron filings trench is not known. There is a potential for precipitation of dissolved minerals within the trench due to pH changes across the trench boundary, resulting in clogging. Therefore, an iron filings trench may require periodic rehabilitation or replacement. Due to the unproven nature of this technology, the potential for high long-term maintenance costs, the lack of source treatment to reduce plume longevity, and the potential for surface discharge of groundwater, an iron filings trench was not selected in any alternative. Nonetheless, the current permeable reaction wall at OU-4 is included in Alternative 1, and should be evaluated as data regarding the effective lifetime and long-term cost of this technology are assessed.

An air sparging curtain could be constructed by installing one or more horizontal, perforated pipes in a gravel-filled trench or numerous vertical wells in a row perpendicular to plume migration. Air injected into the pipes or wells rises through the contaminated groundwater and strips volatiles from the groundwater, transferring them into the vadose zone. If necessary to meet air quality standards, soil vapor extraction (SVE) and aboveground treatment systems could be installed to capture and treat the stripped volatiles. Some researchers have cast doubt on the long-term effectiveness of air sparging. Problems such as channeling, which consists of preferential migration of injected air along specific (more permeable) flow paths rather than uniform air dispersal in the zone surrounding the perforated pipe, have been cited. The occurrence of channeling could reduce the integrity of the sparging curtain in some areas, and allow contaminants to migrate past the curtain. However, the potential for channeling in a homogenous, gravel-filled trench is reduced. Air sparging in the relatively homogeneous sandy soils below the upland terrace near the toe of the CAH plume should be effective without the aid of a gravel trench.

A small percentage of the injected air in an air sparging system would most likely become dissolved in the groundwater, increasing the DO content within the sparging trench and for some distance downgradient from the system. As described in Section 4.4.6.1, DO represents an alternate electron acceptor that, if used preferentially over CAHs, may inhibit the occurrence of reductive dechlorination within the northeast or southeast/east plume lobes. However, less-chlorinated biodegradation daughter products from anaerobic and abiotic processes (e.g., DCE isomers, VC, DCAs, and CB) would potentially be aerobically biodegraded in part to the increased oxygen delivery to the groundwater aquifer. 1,1,1-TCA is not known to be aerobically biodegradable. Air sparging is potentially feasible at the OU-4 site, but was not retained for detailed evaluation due to planned groundwater extraction and treatment near monitoring wells MW-112 and MW-117 by IT Corporation. Air sparging or an iron fileings trench could be reconsidered at a later date if groundwater pump and treat

operations do not reduce/control groundwater contamination at the site to the satisfaction of the SCDHEC.

Contaminated soils near the plume hotspot at MPC could be excavated for the most rapid reduction of the contaminant plume. Modeling results indicate that groundwater velocities are sufficiently high that a rapid decrease in the leachable mass of CAHs in the source area would result in dramatic reduction of CAH concentrations across the plume within 2 to 3 years. However, the extent of soil contamination would first need to be further defined with a soil gas survey and/or additional soil sampling. Unless the volume of contaminated soils in the source area was less than 2,000 cubic feet, the benefits of soil excavation may be offset by the costs associated with contaminated soil excavation, treatment, and disposal. In addition, soil excavation conflicts with AFCEE's waste minimization requirements. The mobile LNAPL detected at the site and much of the residual soil contamination appears to border the water table at a depth of approximately 12 feet bgs, and potentially extends over several thousand square feet. Therefore, the potentially excessive cost of soil excavation combined with the potentially large volume of soil that would require *ex situ* treatment and disposal, precluded further evaluation of this option in this TS.

6.3 BRIEF DESCRIPTION OF REMEDIAL ALTERNATIVES

This section describes how remedial technologies retained from the screening process were combined into two remedial alternatives for OU-4. Sufficient information on each remedial alternative is provided to facilitate a comparative analysis of effectiveness, implementability, and cost in Section 6.4.

6.3.1 Alternative 1--RNA and Institutional Controls with Long-Term Groundwater and Surface Water Monitoring

RNA is achieved when naturally occurring attenuation mechanisms bring about a reduction in the total mass of a contaminant in the soil or dissolved in groundwater. RNA results from the integration of several subsurface attenuation mechanisms that are classified as either destructive or nondestructive. Destructive attenuation mechanisms include biodegradation, abiotic oxidation, and hydrolysis. Nondestructive attenuation mechanisms include sorption, dilution (caused by dispersion and infiltration), and volatilization. In some cases, RNA will reduce dissolved contaminant concentrations below numerical concentration goals intended to be protective of human health and the environment. As indicated by the evidence of RNA described in Section 4, these processes are occurring at OU-4.

Implementation of Alternative 1 would require the use of institutional controls such as land use restrictions and LTM. Land use restrictions may include placing long-term restrictions on soil excavation in the source area, on groundwater well installations within and downgradient from the plume area, and on use of Long Branch Creek east of the site. The intent of these restrictions would be to reduce potential receptor exposure to contaminants by legally restricting activities within areas affected by site-related contamination.

Public education on the selected alternative would be developed to inform Base personnel and residents of the scientific principles underlying RNA. This education

could be accomplished through public meetings, presentations, press releases, and posting of signs where appropriate. Periodic site reviews also could be conducted using data collected during the LTM program. The purpose of these reviews would be to evaluate the extent of contamination, assess contaminant migration and attenuation through time, document the effectiveness of institutional controls at the site, and reevaluate the need for additional remedial actions at the site.

The numerical model described in Section 5 was used to simulate the long-term effectiveness of this alternative. The simulation setup and results are described in detail in Section 6.4.1.

6.3.2 Alternative 2—SVE of the 1,1,1-TCA Source, RNA, and Institutional Controls with Long-Term Groundwater and Surface Water Monitoring

Alternative 2 is identical to Alternative 1 except that a SVE system would be installed within the main source area creating the east/southeast 1,1,1-TCA contaminant plume lobe (near MPC). This system would treat the residual LNAPL source at this location and also promote volatilization of VOCs from mobile LNAPL, thereby treating the groundwater "hot spot" near MPC and reducing discharge to Long Branch Creek.

According to Cohen and Mercer (1993), dissolved contaminant concentrations greater than 1 percent of the aqueous solubility are highly suggestive of NAPL presence. For 1,1,1-TCA, 1 percent of the aqueous solubility is 13,600 µg/L. Therefore, the presence of dense non-aqueous phase liquid (DNAPL) cannot be ruled out.

Despite the desirability of source reduction/removal, it may be technically difficult to achieve given the fact that DNAPL may be present beneath OU-4 and that significant LNAPL contamination may reside in a thin layer bordering the water table. However, simulation of this alternative using the numerical MODFLOW/MT3D$^{96®}$ model indicates how the plume would be affected in the future if the source could be at least partially remediated. Without source removal/reduction, implementation of other remedial actions (e.g., proposed groundwater pump-and-treat as an interim remedial action) would be complicated by the fact that the remedial system(s) would have to operate indefinitely due to the potential longevity of the source.

SVE is applicable for OU-4 because soils are highly permeable, which would allow efficient air movement and oxygen transport. Moderate seasonal changes in water table elevation at the site (historically observed to fluctuate by as much as two feet) would expose more contaminated soils to the effects of SVE during low-water periods and cause an increase in vapor flow to the extraction well. The induced vapor flow volatilizes adsorbed and free-phase contaminants and removes them from the liquid phase.

Extracted soil vapor could be released to the atmosphere if contaminant concentrations are below state discharge requirements. Alternatively, vapor could initially be treated through catalytic oxidation. The catalytic oxidation system would be used to treat initially high VOC concentrations at the site. After VOC concentrations were reduced, the catalytic oxidation system could be taken off-line and replaced by granular activated carbon (GAC) beds. The catalytic oxidation system purifies

contaminated air streams by heating and then destroying the contaminant vapors by contact with an oxidation catalyst. The SVE blower would discharge VOC laden soil gas through a heat exchanger where it is preheated prior to transfer to the catalyst chamber. Once heated, the vapor laden air mixture passes through the catalyst for exothermic destruction. The gases are cooled and scrubbed for subsequent treatment of hydrochloric acid (HCl), a byproduct of catalytic destruction of chlorinated VOCs.

After several months of SVE operation with a catalytic oxidizer, soil gas concentrations may be low enough to use GAC beds for emission treatment. GAC removes VOCs from soil gas by sorbing the VOC to the surface area of the GAC. GAC treatment is more economical for low VOC concentration waste streams and can achieve good removal efficiencies. Periodic replacement of the GAC beds would be required as their available surface area becomes saturated.

A small pilot-scale study would need to be implemented to determine the appropriate number of extraction wells, well radius, available screen area, vacuum configuration, and extraction rates of an SVE system. In order to evaluate the effectiveness of this remedial option, the numerical model was used to simulate the reasonable effects of source reduction through SVE in the source area of the east/southeast source area of the CAH plume. The simulation setup and results are described in detail in Section 6.4.2.

6.4 EVALUATION OF ALTERNATIVES

This section provides a comparative analysis of each of the remedial alternatives based on the effectiveness, implementability, and cost criteria. A summary of this evaluation is presented in Section 6.5.

6.4.1 Alternative 1--RNA and Institutional Controls with Long-Term Groundwater and Surface Water Monitoring

6.4.1.1 Effectiveness

The Visual MODFLOW and MT3D$^{96®}$ codes were used to simulate plume migration if no engineered remedial actions are performed. Model OU4MODA was run for 100 years beyond 1997. Although it is realistic to assume that the source strength will decrease over time due to the effects of leaching and weathering/degradation, the rate of decrease cannot be predicted with confidence due to the lack of information regarding the nature and location of the source. Cohen and Mercer (1993) state that factors influencing NAPL dissolution and eventual depletion include the effective aqueous solubility of NAPL components, groundwater velocity, NAPL-water contact area, and the molecular diffusivity of the NAPL chemicals in water. The actual dissolution of NAPL will generally slow with time due to aging and reduction of the NAPL-water contact area (Powers *et al.*, 1991).

The presence of LNAPL (and potentially DNAPL) at OU-4 could conceivably result in significantly elevated dissolved concentrations of chlorinated solvent, specifically 1,1,1-TCA, for generations. As mentioned in Section 4.1, a cosolvenated fuel/solvent LNAPL was identified at monitoring point MPC, whereas a fuel LNAPL was identified at monitoring point MPB. A product sheen of unknown type was observed at monitoring point MPD. Each of these LNAPL locations is susceptible to weathering,

especially considering the warm surface temperatures, the close proximity of the groundwater surface to the ground surface, and high soil permeabilities which enhance volatilization and precipitation-induced leaching.

For prediction purposes, the contaminant sources at OU-4 were predicted to decrease at a geometric rate of 3 percent per year starting in May 1997. At this rate, the source strengths decreased by 26 percent by simulation year 10 (calendar year 2007) and by 46 percent by simulation year 20 (calendar year 2017). This source reduction scenario reflects both the potential for significant dissolved groundwater contamination for many years, and the likelihood that the source strength will decrease over time.

Figure 6.1 presents the migration of the calibrated total CAH plume over time predicted by Model OU4MODA under the influence of RNA alone. Rapid groundwater velocities cause the plume to discharge to Long Branch Creek before the CAHs can be completely biodegraded. As mentioned in Section 4, the approximate migration time for a contaminant molecule to travel from the former fire training berm to the creek estimated to be approximately 2 years. This migration rate results in rapid stabilization of the plume and little variation in the plume length or width is predicted during much of the 100-year simulation period. Observed CAH concentrations within the source area and downgradient at the edge of Long Branch Creek in May 1997 are predicted to be maximum groundwater concentrations. The model predicts that these concentrations will diminish (at monitoring point MPC) to 26,040 μg/L, 19,190 μg/L, 7,700 μg/L, and 1,440 μg/L for calendar years 2007, 2017, 2047, and 2097, respectively. Similarly, maximum dissolved CAH concentrations at Long Branch Creek are predicted to decrease steadily to 101 μg/L by calendar year 2097.

Figure 6.2 depicts the simulated decreases in 1,1,1-TCA concentrations over the same 100-year time period. 1,1,1-TCA was assumed to represent approximately 56 percent of the total CAH plume mass at OU-4. This ratio was determined by calculating the weighted average of 1,1,1-TCA relative to total CAH contamination for each well where 1,1,1-TCA was detected. The total CAH plume was then converted to 1,1,1-TCA concentrations using the 56 percent ratio. Calculations are included in Appendix C. By using a weighted average, the high 1,1,1-TCA concentrations in the source area cause the simulated 1,1,1-TCA concentrations at the periphery of the plume to be biased high. The model indicates that maximum 1,1,1-TCA concentrations in groundwater will not achieve the current interim remedial goal of 1,000 μg/L at the site within the next 95 years at a geometric source weathering rate of 3 percent per year. Figure 6.3 is a graphic showing predicted 1,1,1-TCA groundwater concentrations versus time in the source area (MPC) and near Long Branch Creek (OBS-A).

6.4.1.2 Technical and Administrative Implementability

Alternative 1 is not technically difficult to implement. Installation of LTM and POC wells and periodic groundwater and surface water sampling and analysis are standard procedures. Long-term management efforts would be required to ensure that proper sampling procedures are followed. Periodic site reviews should be conducted to confirm the adequacy and completeness of LTM data and to verify the effectiveness of

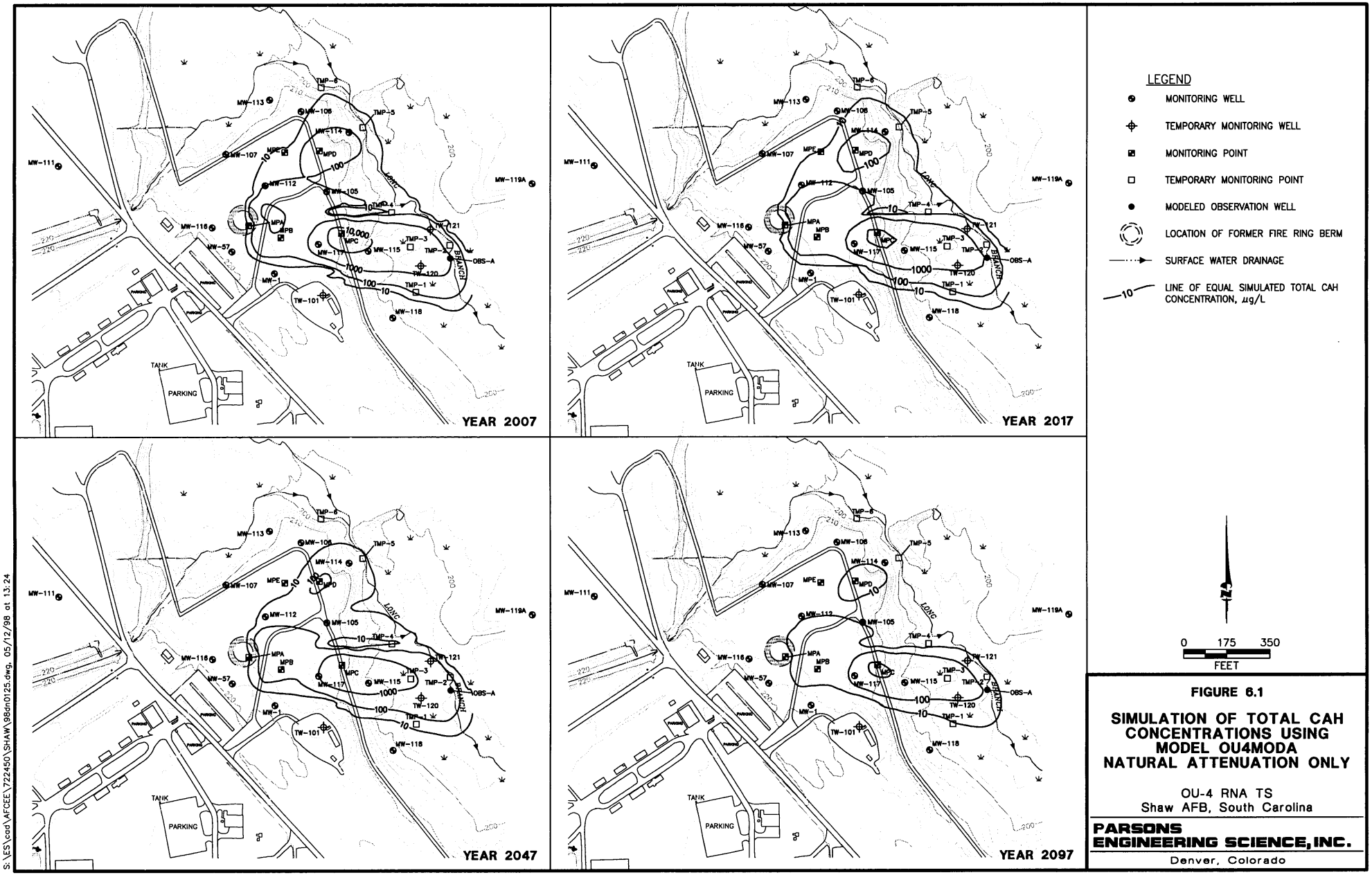

FIGURE 6.1

SIMULATION OF TOTAL CAH CONCENTRATIONS USING MODEL OU4MODA NATURAL ATTENUATION ONLY

OU-4 RNA TS
Shaw AFB, South Carolina

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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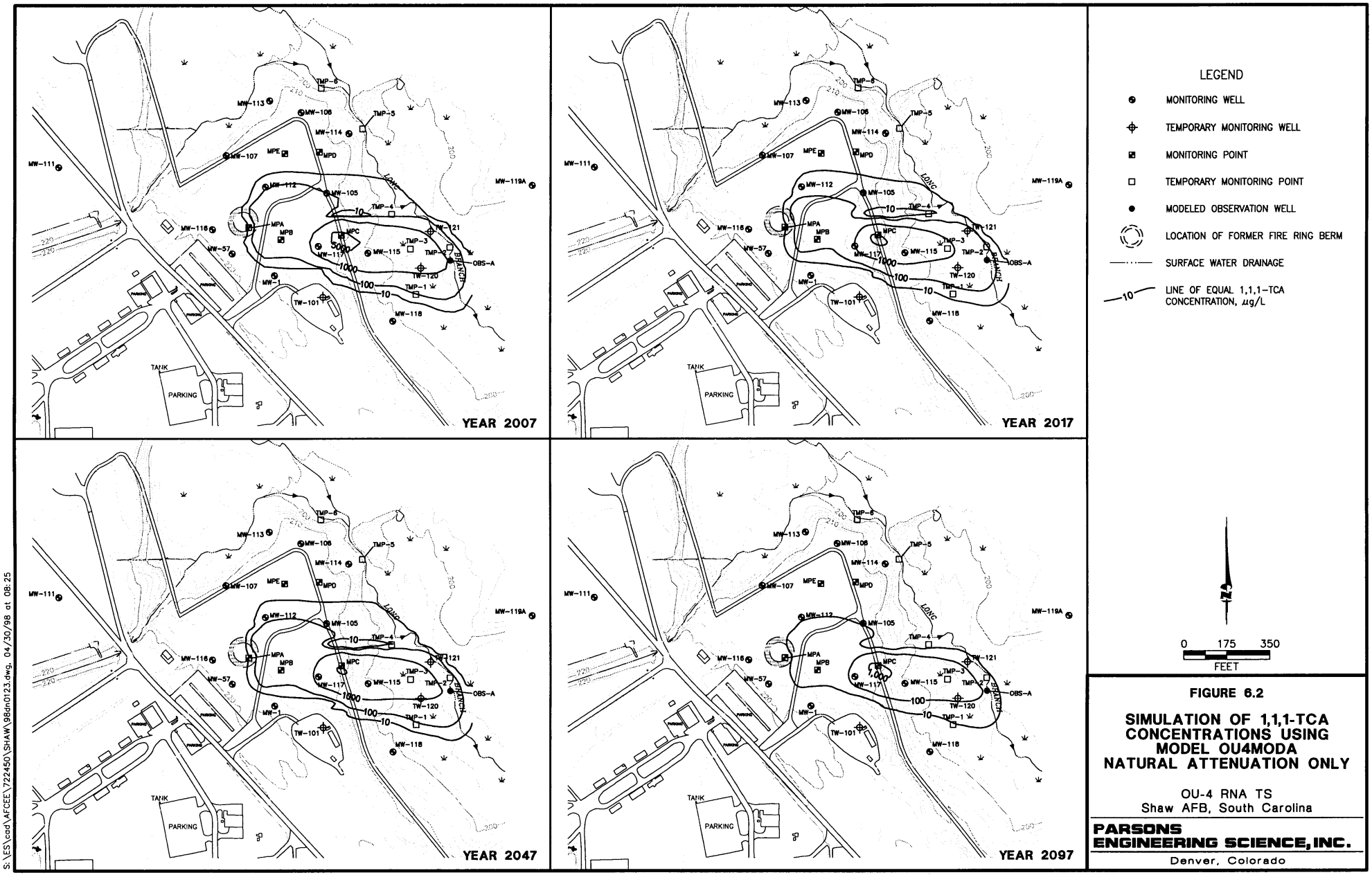

FIGURE 6.2

SIMULATION OF 1,1,1-TCA CONCENTRATIONS USING MODEL OU4MODA NATURAL ATTENUATION ONLY

OU-4 RNA TS
Shaw AFB, South Carolina

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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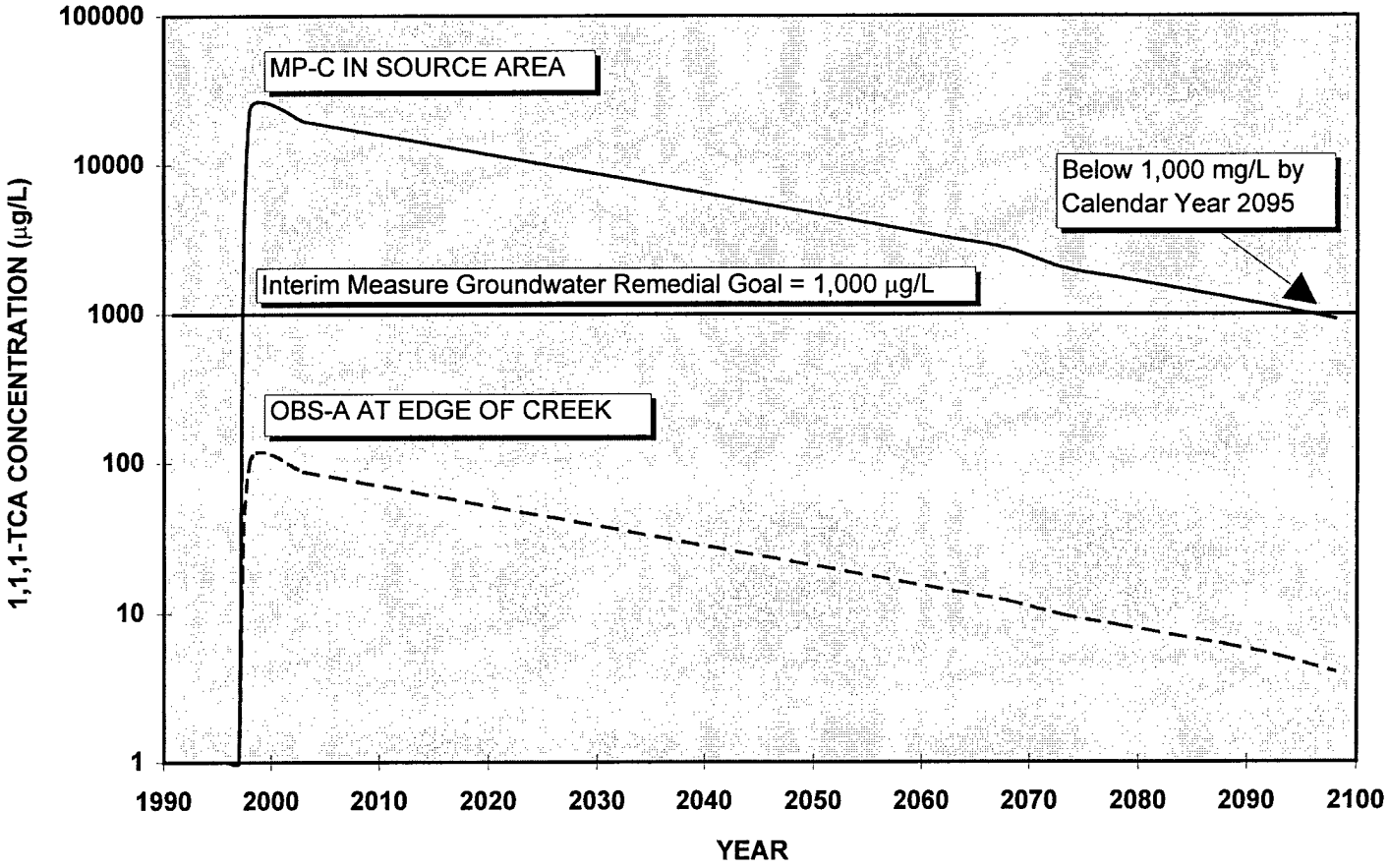
FIGURE 6.3
PLOT OF 1,1,1-TCA CONCENTRATIONS VERSUS TIME
FOR MODEL OU4MODA
OU-4 RNA TS
SHAW AFB, SOUTH CAROLINA



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this remediation approach. However, there may be administrative concerns associated with long-term enforcement of groundwater use restrictions. Given the assumptions regarding the future magnitude and duration of the CAH source, specifically 1,1,1-TCA, that are incorporated into the predictive models, substantially elevated 1,1,1-TCA concentrations are predicted to persist in groundwater for nearly a century. Future land use within the plume area may be impacted by leaving contaminated soil and groundwater in place. Regulators and the public will have to be informed of the benefits and limitations of the RNA option, but educational programs are not difficult to implement.

6.4.1.3 Cost

The present-worth cost of implementing Alternative 1 for a 20-year period beginning in 1998 is summarized in Table 6.3. Included in the total present-worth cost of $232,110 are the estimated costs for installing additional LTM and sentry wells, performing the recommended groundwater and surface water monitoring (see Section 7), maintaining institutional controls, public education, project management, and reporting. Cost calculations are contained in Appendix E.

6.4.2 Alternative 2 - SVE of the 1,1,1-TCA Source, RNA, and Institutional Controls with Long-Term Groundwater and Surface Water Monitoring

6.4.2.1 Effectiveness

Model OU4MODA, used to simulate the effectiveness of Alternative 1 (Section 6.4.1.1), was modified to include the effects of a SVE system operating in the source area of the east/southeast CAH plume lobe near MPC. The SVE system was assumed to begin operation in the fall of 1998 after proposed pilot scale testing in the summer of 1998; the system was assumed to operate for a total of 5 years until calendar year 2003.

The resulting model, termed OU4MODB, assumes annual geometric source reduction of 8-percent during years 1 and 2 of SVE system operation, 5-percent reduction during years 3 through 5, and 3-percent reductions for the remainder of the model simulation. At this rate, 1,1,1-TCA source area concentrations are predicted to undergo reductions of 38 percent by 5 years and 54 percent by 20 years. The model assumes that SVE will not be implemented at other potential source areas in the former fire training berm and northeast of the berm near monitoring point MPD. These source areas were assumed to naturally weather at a geometric rate of three percent per year.

It should be noted that the effectiveness of a SVE system at remediating the CAH source cannot be predicted with accuracy because the nature and extent of the source is unknown. If the source of the east/southeast plume lobe primarily borders the water table, SVE would be most effective during seasonal groundwater lows. Groundwater elevations measured in May 1997 were approximately 2 feet lower than groundwater elevations measured in March 1993. This suggests that the NAPL layer may have been thicker in May 1997 because more residual contamination was exposed that could result in NAPL formation. However, temporal water table fluctuations are beneficial to SVE because more residual contamination can be exposed to SVE than if the water table elevation did not fluctuate. Therefore, the results of the model simulations incorporating SVE are speculative and the effectiveness of SVE could be greater or less

TABLE 6.3
ESTIMATED ALTERNATIVE 1 COSTS
OU4 RNA TS
SHAW AFB, SOUTH CAROLINA

Capital Costs	Present Worth Cost
Design/construct three LTM wells and one sentry well in 1998	$12,450
Monitoring Costs	**Present Worth Cost**
Conduct annual groundwater monitoring of 11 wells and 6 surface water stations from 1998 to 2002	$97,264
Conduct biennial groundwater monitoring of 11 wells and 6 surface water stations from 2003 to 2018	$57,390
Site management (maintain institutional controls/public education) (20 years)	$65,010
Total Present Worth of Alternative 1 [a/]	**$232,110**

a/ Based on an annual adjustment factor of 7 percent (USEPA, 1993).
Note: Costs assume that well installation and LTM are performed by local (Sumter/Columbia) personnel.

than predicted. However, the simulations indicate how engineered source reduction, if feasible, would affect the CAH and 1,1,1-TCA concentrations.

The results of a SVE pilot test performed in the former fire training berm in February 1993 indicated that significant soil vacuums were generated at the site with a pore volume turnover rate of at least 24 per day (Rust E&I, 1993). The radius of influence of vertical SVE extraction wells was limited due to the presence of a perched groundwater layer and confining clay sequence at approximately three to five feet bgs. The results of this study suggested that SVE is possible at the site, but its effectiveness may be limited by the geology beneath the fire training berm area. Because sandy soils are prevalent near MPC, an SVE system installed at this location would be expected to achieve better NAPL removal rates than measured at the visible fire training berm.

The CAH plume migration simulated by Model OU4MODB is shown on Figure 6.4. SVE reduces the maximum dissolved CAH concentration in the plume from 30,240 µg/L in 1997 to 13,530 µg/L by year 2018; therefore, maximum CAH concentrations within the plume are reduced more rapidly than in the Alternative 1 simulations (Section 6.4.1). Plume concentrations and extents tend to be similar to those predicted in model OU4MODA, except that overall concentrations are reduced approximately 12 percent faster by calendar year 2008 in model OU4MODB.

FIGURE 6.4

SIMULATION OF TOTAL CAH CONCENTRATIONS USING MODEL OU4MODB NATURAL ATTENUATION WITH SOIL VAPOR EXTRACTION IN THE SOURCE AREA

OU-4 RNA TS
Shaw AFB, South Carolina

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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Simulated 1,1,1-TCA concentrations derived from model OU4MODB are shown on Figure 6.5. Although 1,1,1-TCA concentration reductions are accelerated in this prediction relative to Model OU4MODA, the areal extent of the plume through time is very similar to that predicted by Model OU4MODA (Figure 6.2). Similar to CAH concentrations, 1,1,1-TCA concentrations diminish approximately 12 percent faster than in Alternative 1 by calendar year 2008 (5 years of SVE and 5 years of normal weathering). 1,1,1-TCA concentrations are not predicted to decrease below 1,000 μg/L at the site within 90 years. Figure 6.6 is a graphic showing predicted 1,1,1-TCA groundwater concentrations versus time in the source area (MPC) and near Long Branch Creek (OBS-A).

6.4.2.2 Technical and Administrative Implementability

The implementability issues described for Alternative 1 in Section 6.4.1.2 also are applicable for Alternative 2. However, administrative concerns regarding the length of LTM and institutional controls may be lessened due to more rapid depletion of significantly elevated dissolved TCE concentrations. Regulatory and community acceptance of this alternative should be more positive than with Alternative 1 due to the more aggressive plume remediation activities.

Alternative 2, as simulated by the numerical model, should not be difficult to implement technically or administratively. However, the nature and extent of the 1,1,1-TCA source near MPC, specifically the LNAPL source, has not been fully defined. Additional site investigation would need to be performed to properly size and locate a SVE system.

The SVE system simulated by model OU4MODB would require construction of approximately 5 SVE wells (assuming a radius of influence of 50 feet for each well) in the vicinity of monitoring point MPC, and installation of an aboveground vacuum blower, catalytic oxidation and GAC emission treatment systems, and associated piping. SVE is assumed to be limited to the area adjacent to monitoring point MPC where fuel/solvent LNAPL was detected.

The requirement for vapor treatment systems (e.g., catalytic oxidation/GAC systems) potentially may be omitted from the design process if appropriate land-use controls can be maintained and vapors may be emitted to the atmosphere. Otherwise, it is recommended that a catalytic oxidation unit with an air scrubber for HCl initially be used at the site to reduce emissions until influent concentrations to the SVE blower were low enough to utilize a cheaper GAC treatment system. Catalytic oxidation and GAC systems are generally reliable when properly maintained. Standard mechanical and electrical construction and equipment would be used; special construction techniques and special-order equipment should not be necessary. All equipment needed for this alternative is commercially available.

Assuming a 5-year-long operating period, the above ground vacuum blower(s) may have to be replaced once over the life of the SVE system. The most significant maintenance requirement for this system will be regular maintenance of the catalytic oxidation system during the (estimated) first 3 months of initial SVE system operation and of the GAC system during the following years to ensure that air emissions standards are attained. Blower systems are very reliable and require only minimal

FIGURE 6.5
SIMULATION OF 1,1,1-TCA CONCENTRATIONS USING MODEL OU4MODB NATURAL ATTENUATION WITH SOIL VAPOR EXTRACTION IN THE SOURCE AREA
OU-4 RNA TS
Shaw AFB, South Carolina

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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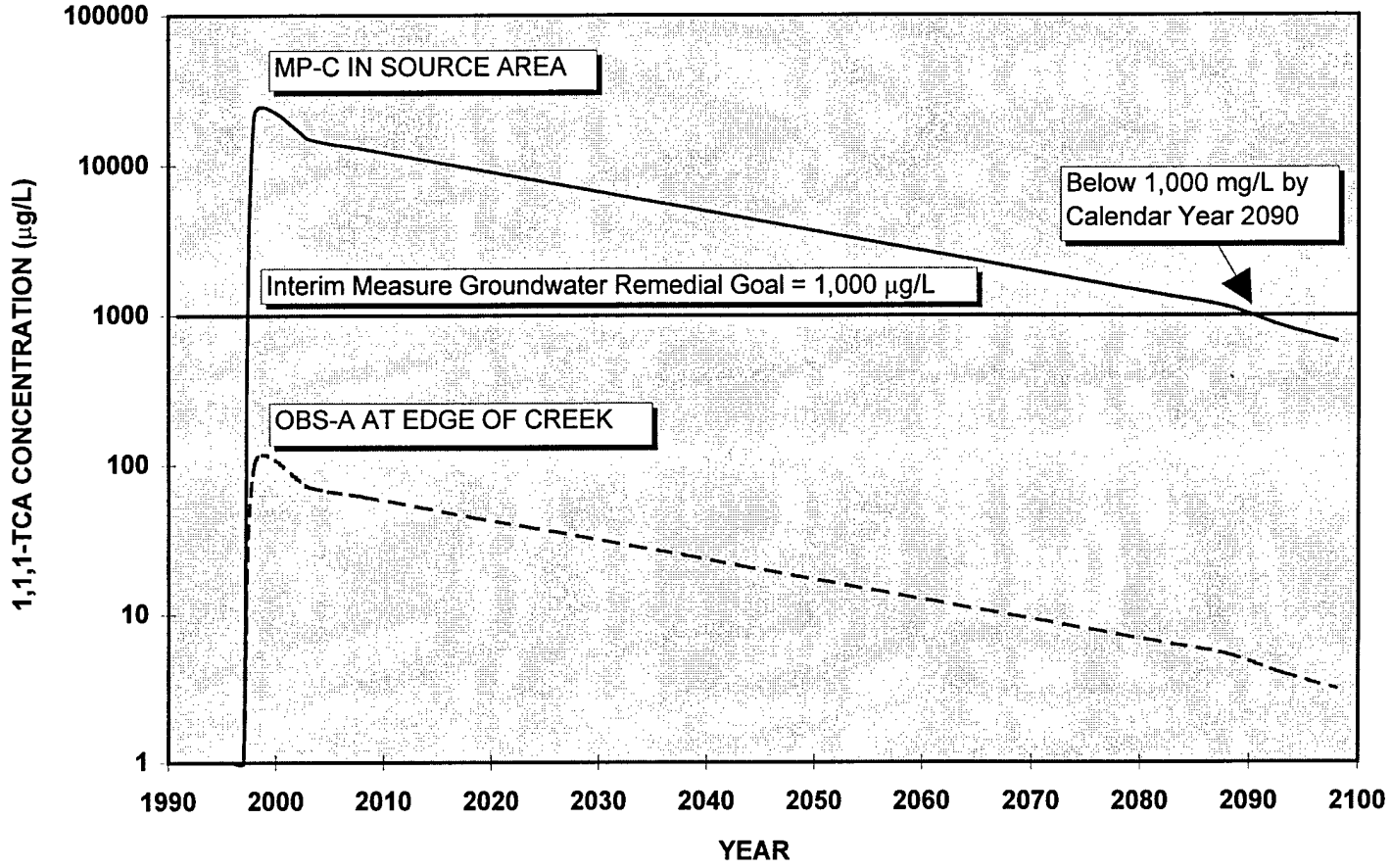
FIGURE 6.6
PLOT OF 1,1,1-TCA CONCENTRATIONS VERSUS TIME
FOR MODEL OU4MODB
OU-4 RNA TS
SHAW AFB, SOUTH CAROLINA



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maintenance. Air filters provide blower protection and generally require replacement every 90 to 180 days. Installation and operation of a full-scale SVE system would require an increased commitment of man-hours and other resources to maintain and monitor the system. Weekly system checks are recommended, and operating data such as vacuum pressure and flow rate should be recorded. Periodic vapor samples would be required to demonstrate compliance with emissions requirements.

Performance of an SVE pilot test would be desirable to obtain design parameters to facilitate design of a full-scale system. The pilot test could potentially be performed using new monitoring wells installed for groundwater pump and treat by IT (SCDHEC, 1998).

Administrative implementation of this alternative will require that appropriate air discharge permits are obtained, and that future development plans protect the SVE system. All system components (above- and below-grade) should be protected against damage in the event that construction or maintenance work is performed in the area.

6.4.2.3 Cost

The estimated capital and operating costs of Alternative 2 are shown in Table 6.4. The total present worth cost of Alternative 2 is approximately $593,590. The cost of Alternative 2 is greater than Alternative 1 due to the addition of the SVE system. It is assumed that the SVE system would be operated for 5 years after installation. Annual LTM would continue for a total of 5 years to build a historical groundwater and surface water quality database, and biennial LTM would be performed for at least an additional 15 years to monitor temporal changes in dissolved CAH concentrations. Cost calculations are contained in Appendix E.

6.5 GROUNDWATER PUMP-AND-TREAT AS AN INTERIM MEASURE TO MONITORED NATURAL ATTENUATION

Shaw AFB currently is seeking monitored natural attenuation as a long-term remedy at OU-4, to be supported, in part, by this TS. However, the SCDHEC has mandated that an IM be implemented to mitigate groundwater migration until monitored natural attenuation can be evaluated at the site. The currently proposed IM for site OU-4 is a groundwater pump-and-treat system to be installed by IT Corporation during the spring/summer of 1998. It is assumed for purposes of this report that the planned groundwater extraction and treatment will be conducted for several years until sufficient groundwater and surface water data can be produced supporting natural attenuation and stabilization/recession of the groundwater plume.

The effects of groundwater pump-and-treat within the source area near monitoring point MPC in combination with natural attenuation were evaluated in model OU4MODC. Specific design information regarding the implementation of the groundwater extraction and treatment system, including anticipated pumping rates, well construction details, and precise locations, were not available at the time of this report, but were being prepared (IT, 1998). Therefore, groundwater pump and treat in model OU4MODC was simulated by a single well located adjacent to MPC and screened from several feet above the water table to approximately 20 feet below the water table.

TABLE 6.4
ESTIMATED ALTERNATIVE 2 COSTS
OU-4 RNA TS
SHAW AFB, SOUTH CAROLINA

Capital Costs	Present Worth Cost
Design/construct three LTM wells and one sentry well in 1998	$12,450
Design/install SVE system in 1998	$115,860

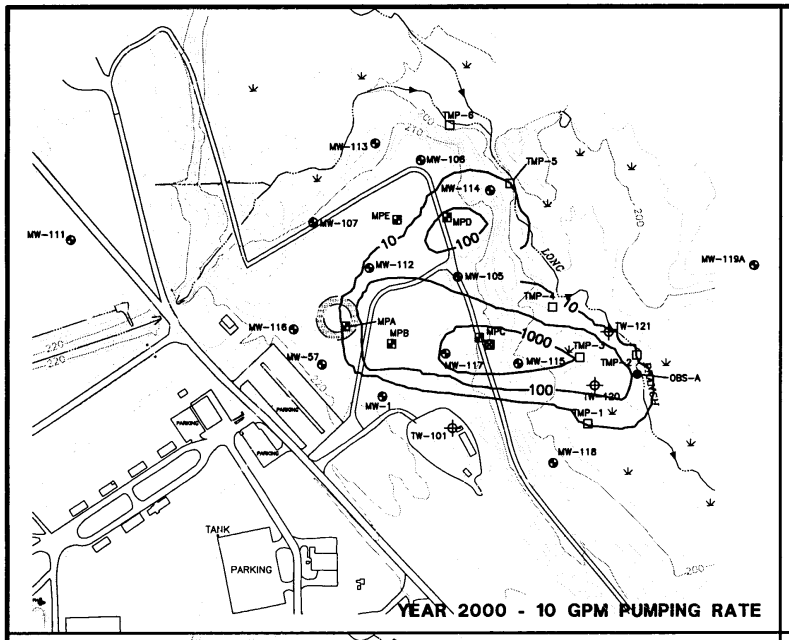
Monitoring and O&M Costs	Present Worth Cost
Conduct annual groundwater monitoring of 11 wells and 6 surface water stations from 1998 to 2002	$97,260
Conduct biennial groundwater monitoring of 11 wells and 6 surface water stations from 2003 to 2018	$57,390
Site management (maintain institutional controls/public education) (20 years)	$65,010
Operate/maintain SVE system (5 years)	$245,620
Total Present Worth of Alternative 2 [a/]	**$593,590**

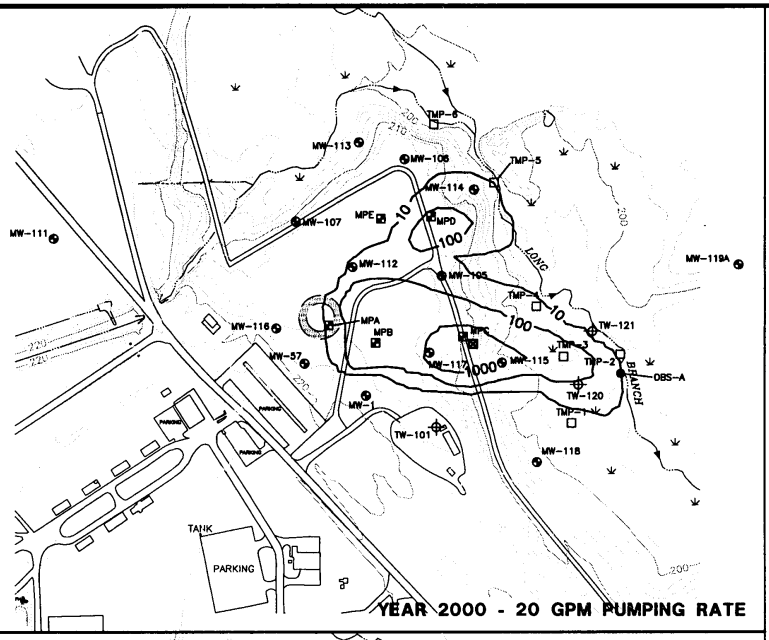
a/ Based on an annual adjustment factor of 7 percent (USEPA, 1993).
Note: Costs assume that well installation, LTM, and O&M are performed by local (Sumpter/Columbia) personnel.

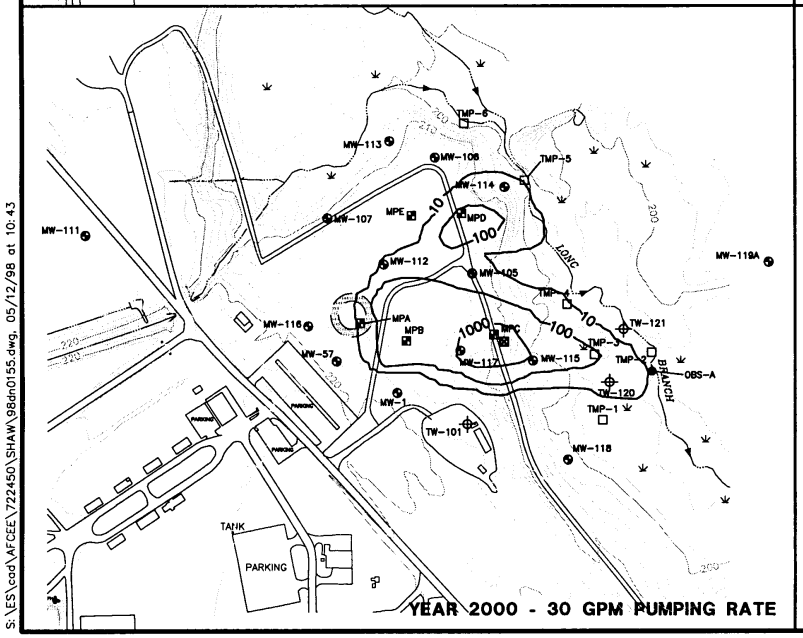
Simulated pumping rates ranging from 10 to 40 gpm were assumed to be feasible given the sandy, relatively permeable soils underlying the site.

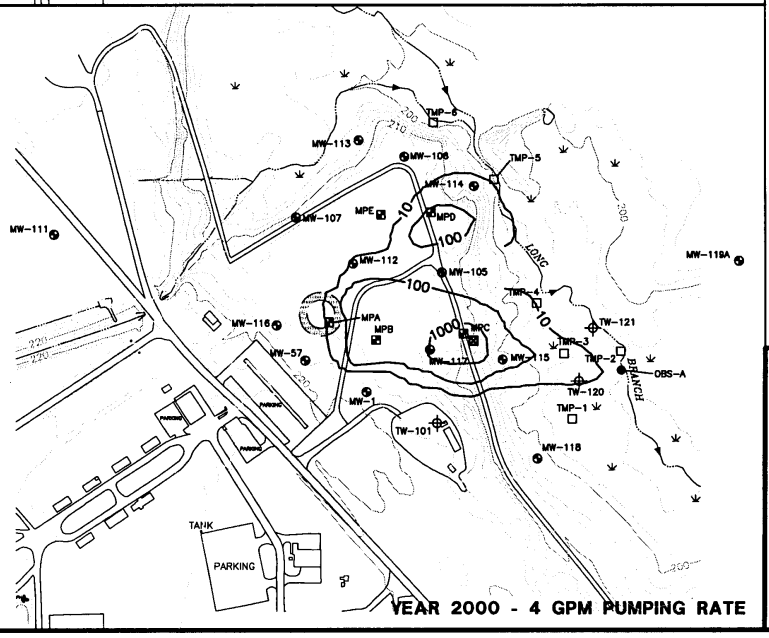
Figure 6.7 presents results from model OU4MODC for the year 2000 at selected pumping rates from 10 to 40 gpm. At the lower pumping rate of 10 gpm, the simulated groundwater plume is similar to the 1997 plume (Figure 4.7), and concentrations of 1,1,1-TCA approaching or exceeding 100 µg/L at the edge of Long Branch Creek may be possible (the maximum 1,1,1-TCA concentration measured adjacent to the creek in May 1997 was 78.6 µg/L at TMP-2). At pumping rates of 20 gpm and above, the 1,1,1-TCA plume begins to recede and downgradient migration of the plume is inhibited by the pumping system. The simulated pumping rate of 40 gpm in model OU4MODC prevented 1,1,1-TCA concentrations greater than 1,000 µg/L from migrating farther than 75 feet downgradient from the pumping well.

The model simulations indicate that beneficial results could be obtained by the implementation of a pump-and-treat system. However, the use of this type of system is costly and requires a high degree of operation and maintenance. Furthermore, the use of groundwater pump and treat will alter the hydraulics (and possibly also the geochemistry) of the groundwater system in the plume area, and current groundwater









LEGEND

- MONITORING WELL
- TEMPORARY MONITORING WELL
- MONITORING POINT
- TEMPORARY MONITORING POINT
- SIMULATED GROUNDWATER EXTRACTION WELL
- MODELED OBSERVATION WELL
- LOCATION OF FORMER FIRE RING BERM
- SURFACE WATER DRAINAGE
- 10 — LINE OF EQUAL SIMULATED 1,1,1-TCA CONCENTRATION, µg/L

NOTE: THE MAPS SHOW THE PREDICTED PLUME CONFIGURATIONS FOR YEAR 2000, AFTER 2 YEARS OF SIMULATED GROUNDWATER EXTRACTION.

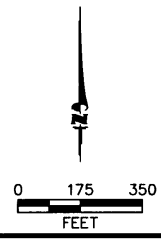


FIGURE 6.7
SIMULATION OF 1,1,1-TCA CONCENTRATIONS USING MODEL OU4MODC-NATURAL ATTENUATION WITH 2 YEARS GROUNDWATER EXTRACTION AT 1,1,1-TCA SOURCE
Site OU-4 RNA TS
Shaw AFB, South Carolina

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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velocity estimates and estimated biodegradation rates used in the predictive models OU4MODA and OU4MODB may be invalidated. The groundwater pump and treat system also may have the negative effect of transporting oxygenated water from outside the source area to within the source area near the extraction well. The addition of oxygenated water to the source area would potentially suppress the microbial communities responsible for reductive dechlorination of CAHs or alter the redox conditions necessary for abiotic dehydrohalogenation of 1,1,1-TCA to 1,1-DCE. It is therefore recommended that groundwater extraction and treatment be used as only a temporary IM (as planned), replaced by remedial alternatives 1 or 2 as discussed in Section 6.6.

6.6 RECOMMENDED REMEDIAL APPROACH

Two alternatives have been evaluated for remediation of the shallow groundwater at OU-4. Components of the alternatives evaluated include SVE, aboveground treatment of extracted vapors, RNA with LTM of groundwater and surface water, and institutional controls. The alternatives were developed to maximize the benefit of RNA in the overall remedial process and to supplement the remedial strategy (if needed) with proven low-cost, non-intrusive source treatment technologies to shorten LTM efforts. Therefore, implementation of the reactive barrier walls installed at the site in 1998 was not evaluated because they remain an unproven technology. The reactive barrier walls will help to limit downgradient contaminant migration, but will not treat the contaminant source and, therefore will not reduce the length of an OU-4 LTM program. Table 6.5 summarizes the results of the evaluation based upon effectiveness, implementability, and cost criteria.

Alternative 1 makes maximum use of natural attenuation mechanisms to reduce plume migration and toxicity. Alternative 2 would reduce plume longevity and provide additional protection against further plume migration, but would still rely on RNA to reduce plume toxicity in the downgradient portions of the affected area. Implementation of Alternative 2 would potentially decrease the time frame required for remediation, but would require greater capital and O&M expenditures.

Each of the alternatives has implementability concerns. Implementation of Alternative 1 may require a very lengthy LTM period, and maintenance of institutional controls in the plume area would be required. However, if future LTM results indicate that the plume is stable or receding, and that surface water standards will not be exceeded, then the frequency of LTM sampling events could be reduced. The installation of reactive barrier walls downgradient of the source is expected to help reduce the frequency of LTM sampling. SVE of the source area could further reduce the duration of LTM, but the effectiveness of SVE may be limited if most of the source is comprised of a thin NAPL layer, which may be seasonally water-saturated. SVE may potentially require more than 5 years to remediate the source if these conditions exist. In addition, if DNAPL is present, it would be unaffected by the SVE system and would continue to be a long-term source of dissolved groundwater contamination. However, without concurrent source reduction, any LTM, planned groundwater extraction and treatment, or maintenance of a reactive barrier wall would have to be performed indefinitely. Implementation of an SVE system (Alternative 2) instead of Alternative 1 (no source treatment) may be more acceptable to the public and regulatory

TABLE 6.5
SUMMARY OF REMEDIAL ALTERNATIVES EVALUATION
OU-4 RNA TS
SHAW AFB, SOUTH CAROLINA

Remedial Alternative	Effectiveness	Implementability	Present Worth Cost Estimate
Alternative 1 - Natural Attenuation - Long-Term Monitoring - Institutional Controls	Contaminant mass, volume, and toxicity will be slowly reduced over time, but due to the potentially large LNAPL source, the dissolved plume may persist for 95 years, necessitating a potentially lengthy period of LTM and institutional controls.	Readily implementable. Groundwater water quality monitoring required for an estimated minimum of 20 years, and potentially much longer. Institutional controls, including land and groundwater use controls, may be required for 95 years due to the persistence of elevated dissolved 1,1,1-TCA concentrations. Minimal exposure to potential receptors if institutional controls are implemented. If significant plume migration occurs and completion of exposure pathways is possible, then additional remedial work may be required.	**$232,110**
Alternative 2 - Soil Vapor Extraction - Natural Attenuation - Long-Term Monitoring - Institutional Controls	Similar to Alternative 1, with the addition of a Soil Vapor Extraction (SVE) system to remove mobile and residual LNAPL. Contaminant mass, volume, and toxicity will be reduced more rapidly than in Alternative 1. However, even if the source is substantially reduced, significantly elevated dissolved CAH, specifically 1,1,1-TCA, concentrations may still persist for 90 years, and downgradient plume migration may continue to reach Long Branch Creek, depending on the effectiveness of SVE and actual biodegradation rates.	Installation/operation of the SVE system simulated by the numerical model should not pose significant implementability concerns. May require the use of catalytic oxidation followed by granular activated carbon treatment to reduce emissions. Long-term site management, groundwater use controls, and monitoring would be required as elevated 1,1,1-TCA concentrations may persist for 90 years. If significant plume migration occurs and completion of exposure pathways is possible, then additional remedial work may be required.	**$593,590**

agencies because it represents the more aggressive remedial approach intended to reduce the duration of LTM.

The estimated present worth cost for Alternative 2 is substantially higher than for Alternative 1 due to the addition of engineered remedial actions. Operation and maintenance of an SVE system would require a more significant annual expenditure of funds during the operational lifetime of this system.

On the basis of this evaluation, Alternative 1 is selected with continued operation of the installed reactive barrier walls. The reactive barrier walls were installed as part of a separate effort, but their partial capture of the CAH plume will affect the sampling frequency of the LTM program because less contamination will reach Long Branch Creek. Available data indicate that the CAH and 1,1,1-TCA plumes are either stabilized or diminishing slowly due to RNA alone, and that 1,1,1-TCA concentrations decrease by more than 2 orders of magnitude between the source area and Long Branch Creek. Data is unavailable to describe current CAH reductions, but the combined affect of RNA and the barrier walls are expected to mitigate contaminant migration into Long Branch Creek. However, the degree to which RNA and the reactive barrier walls will continue to prevent significant downgradient migration of the plume is not known with certainty and will become more apparent as successive LTM sampling events are performed. A reduction of the sampling frequency for LTM might be reached sooner if the reaction wall and RNA continue to be effective. Model predictions suggest that the IM groundwater remedial goal of 1,000 μg/L for 1,1,1-TCA may not be attained for 95 years without source treatment.

If future LTM data indicate that 1,1,1-TCA discharge to Long-Branch Creek is a concern despite RNA and the reactive barrier walls, then Alternative 2 may be implemented as a contingency. Implementation of Alternative 2 will require further contaminant source delineation and characterization. Source delineation could be performed using minimally intrusive soil gas survey (passive or active) techniques to identify 1,1,1-TCA and CAH "hot spots" that may correspond to a NAPL source area. An active soil gas survey involves driving a perforated probe into the shallow subsurface and extracting soil gas using a vacuum pump. The gas sample can be analyzed onsite for the contaminant(s) of concern (COCs) using a gas chromatograph (GC). A potential advantage of an active survey is that variations in soil gas quality with depth can easily be investigated by collecting samples at multiple depths. Increases in contaminant concentrations with depth indicate the presence of a subsurface source as opposed to a surficial source.

With a passive soil gas survey, an absorbent collector is placed a few inches to a few feet below the ground surface for a period of time, and is then removed and analyzed onsite or at a fixed-base laboratory for the COCs. A potential advantage of a passive survey is that passive collectors tend to be more sensitive to subsurface contaminant concentrations because they are left in place over a period of time. Prior to performing a full-scale survey, both active and passive samples could be collected at a small number of locations and the results compared to determine the optimal method for the OU-4 area.

The estimated cost for a 150-point passive soil gas survey is approximately $30,000. This cost includes a letter work plan, sampler installation/removal, laboratory analysis,

and a results letter report. If one or more CAH "hot spots" are identified from the passive soil gas survey, then drilling and soil/groundwater sampling would be required to further define subsurface physical and chemical conditions and costs would vary accordingly.

Under any scenario (Alternative 1 or 2 with reactive barrier walls), model results suggest that the drinking water criterion and aquatic life standard for 1,1,1-TCA will not be exceeded in Long Branch Creek at any time in the future. This conclusion is supported by the lack of quantifiable 1,1,1-TCA detections in Long Branch Creek. In addition, the shallow groundwater at the site and surface water in the on-Base reach of Long Branch Creek are not being used as drinking water or irrigation sources, and may not represent viable water sources due to the currently restricted nature of the Base. During and after source removal activities, if LTM results demonstrate that the plume is stable or receding and surface water standards are not exceeded, then the frequency of LTM could potentially be reduced (e.g., to once every 2 years or more).

SECTION 7

LONG-TERM MONITORING PLAN

7.1 OVERVIEW

In keeping with the requirements of the preferred remedial alternative for OU-4 (Section 7), a long-term groundwater monitoring plan was developed. The purpose of this component of the preferred remedial alternative for the site is to assess site conditions over time and the effectiveness of naturally occurring processes at reducing contaminant mass and minimizing contaminant migration, and evaluate the need for additional remediation.

The long-term groundwater monitoring plan for OU-4 presented in this section describes a monitoring scheme for the next 20 years for planning and budgeting purposes. It should be noted that this plan was devised on the basis of currently available data; the LTM program may be progressively revised as new data are obtained during this 20-year period. The LTM plan consists of identifying the locations of LTM wells and developing a groundwater sampling and analysis strategy to accomplish the following objectives:

- Monitor changes in site conditions, including plume magnitude and extent, over time;
- Evaluate the 1,1,1-TCA degradation rate and assess the effectiveness of naturally occurring processes at reducing contaminant mass and minimizing contaminant migration;
- Assess the need for additional remediation; and
- Verify the predictions of the numerical contaminant fate and transport model.

The strategy described in this section is designed to monitor plume migration over time and to verify that natural and engineered remedial processes are adequately protecting potential receptors. In the event that data collected under this LTM program indicate that naturally occurring processes are insufficient to adequately protect human health and the environment, contingency controls to more aggressively remediate the dissolved 1,1,1-TCA plume would be necessary.

7.2 MONITORING NETWORKS

Two separate types of wells will be used at the site as part of the LTM program. The first type consists of LTM wells to verify the results of the MODFLOW/MT3D modeling and to ensure that natural attenuation is occurring at rates sufficient to

adequately limit plume expansion and deleterious impact to surface water standards. The second type of well consists of a sentry well to verify that no 1,1,1-TCA exceeding IM groundwater quality guidelines migrate beyond the area under institutional control.

7.2.1 Groundwater Monitoring Network and Sampling Frequency

Annual LTM of three new LTM wells and 8 existing monitoring wells located within the CAH plume is recommended. The locations of the proposed and existing wells to be sampled are shown on Figure 7.1. Three of the proposed LTM wells are located along the approximate centerline of the east/southeast contaminant plume lobe to help monitor the progress of natural attenuation. These proposed LTM wells also were positioned to further delineate maximum plume concentrations, especially in the source area near MPC where no permanent well currently are located. The existing wells to be sampled include MW-105, MW-112, MW-113, MW-114, MW-115, MW-116, MW-117, and MW-118 (Figure 7.1). Well MW-116 is located upgradient from the majority of the plume, and the remaining wells are located within or transverse to the contaminant plume lobes. The transverse well locations are intended to monitor any potential expansion of the plume in the future. For scoping and costing purposes, this LTM plan assumes that all selected LTM wells initially will be sampled annually. Performance of annual sampling for 5 years (1998 through 2002) is recommended to build a historical water quality database for the site.

Following completion of the 5-year annual LTM period, biennial (every other year) LTM of all wells for an additional 15 years (2003 through 2018) is assumed. Estimates of the groundwater/CAH migration rate and direction should be progressively refined as new data are obtained to aid in plume definition and tracking. In addition, the LTM results can be compared to model-predicted concentrations to assess whether the numerical model has accurately simulated plume persistence over time.

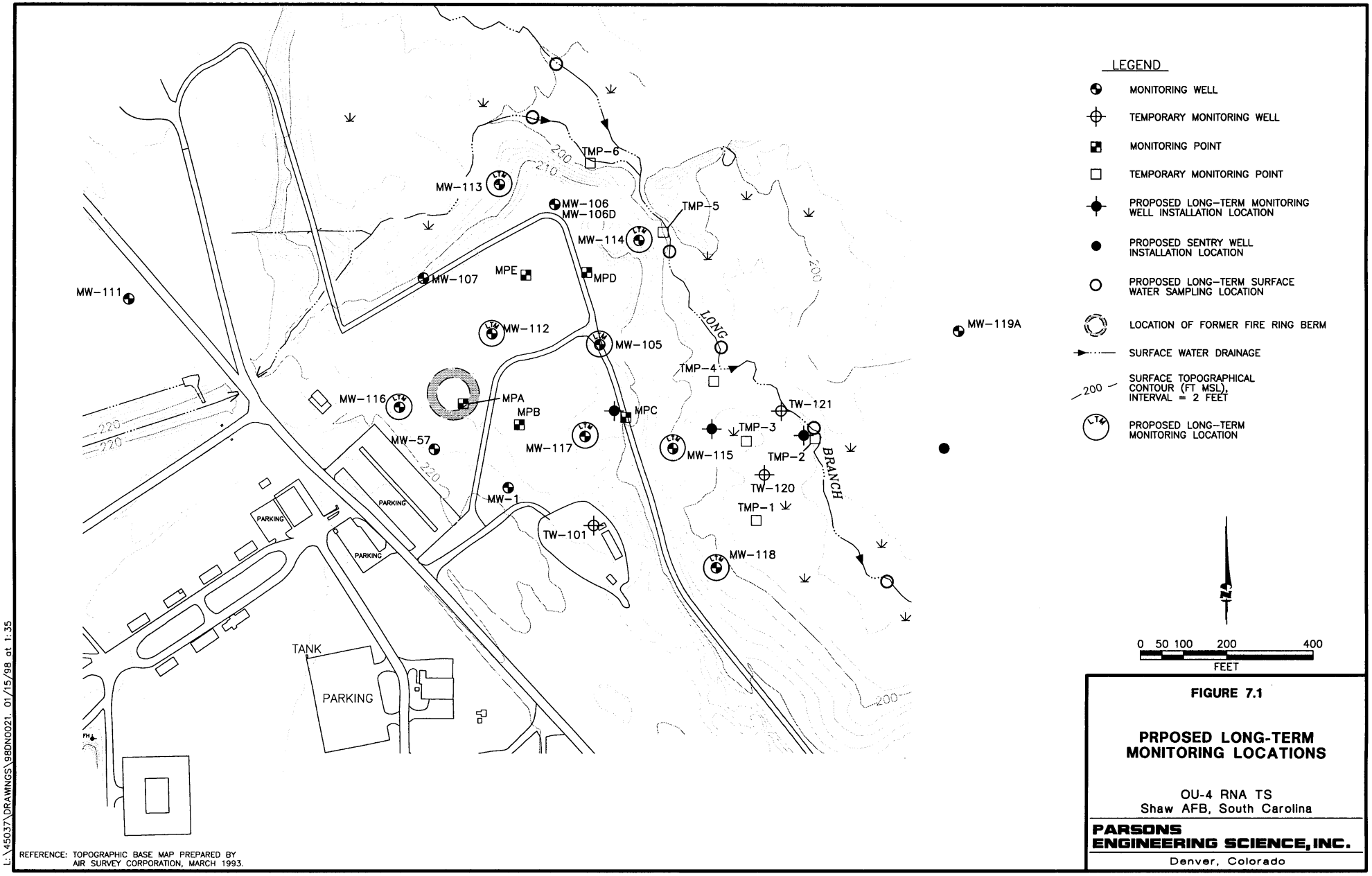
7.2.2 Sentry wells

The second type of monitoring well to be used at OU-4 is a sentry well. A single sentry well is proposed approximately 300 feet east of Long Branch Creek at the point of maximum contaminant discharge. The purpose of the sentry well is to confirm that the dissolved plume is not migrating beyond the area under institutional control. The preliminary sentry well location is shown on Figure 7.1.

7.3 SURFACE WATER MONITORING NETWORK AND SAMPLING FREQUENCY

Annual sampling of a minimum of six surface water stations during the 5-year annual LTM period described above is recommended. The six stations are located along Long Branch Creek upstream, within, and downstream from the reach projected to receive contaminant discharge (Figure 7.1). Data from these samples will be used to evaluate the impact of groundwater discharge on the quality of the surface water, and the effects of natural attenuation (e.g., dilution, volatilization) on contaminant concentrations (if any) in the creek.

The need for additional surface water quality monitoring following completion of the 5-year annual monitoring period should be assessed on the basis of the monitoring



REFERENCE: TOPOGRAPHIC BASE MAP PREPARED BY AIR SURVEY CORPORATION, MARCH 1993.

L:\45037\DRAWINGS\98DN0021. 01/15/98 at 1:35

FIGURE 7.1

PRPOSED LONG-TERM MONITORING LOCATIONS

OU-4 RNA TS
Shaw AFB, South Carolina

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

results. Biennial monitoring of surface water for 15 years starting in year 2004 is assumed for costing purposes.

7.4 ANALYTICAL PROTOCOL

All LTM wells should be sampled and analyzed to determine compliance with chemical-specific remediation goals and to verify the effectiveness of remediation at the site. Groundwater level measurements should be made during each sampling event. Groundwater samples from LTM wells should be analyzed for the parameters listed in Table 7.1. Surface water samples should be analyzed for VOCs using USEPA Method 8260b or 8021b.

7.5 PERIODIC LTM PLAN REVIEW

The LTM plan should be periodically reviewed and revised as appropriate on the basis of available groundwater quality data. For example, if the sampling results obtained during the 15-year biennial sampling period demonstrate that the plume is in equilibrium (not receding or migrating downgradient) or is receding back toward the source area, then the sampling frequency could be reduced appropriately. If the data collected at any time during the monitoring period indicate the need for additional remedial activities at the site, sampling frequency should be adjusted accordingly. If sampling results indicate that geochemical conditions in the plume area are stable over time (e.g., nitrate, sulfate, and ferrous iron concentrations), then the sampling frequency for these parameters could be reduced.

TABLE 7.1
LONG-TERM GROUNDWATER MONITORING ANALYTICAL PROTOCOL
OU-4 RNA TS
SHAW AFB, SOUTH CAROLINA

Analyte	Method/Reference	Comments	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Field or Fixed-Base Laboratory
Ferrous Iron (Fe^{2+})	Colorimetric A3500-Fe D or Hach 25140-25	Filter if turbid	May indicate an anaerobic degradation process due to the depletion of oxygen, nitrate, and manganese	Each sampling event	Collect 100 mL of water in a glass container; for Method A3500-FeD, acidify with hydrochloric acid per method	Field
Temperature**	E170.1, direct-reading meter	Measure at well-head	Purging adequacy; metabolism rates for microorganisms depend on temperature	Each sampling event	Measure at well-head using a flow-through cell	Field
Dissolved Oxygen**	Dissolved oxygen meter	Measure at well-head; refer to Method A4500 for a comparable laboratory procedure	Purging adequacy; concentrations less than 1 mg/L generally indicate an anaerobic pathway	Each sampling event	Measure at well-head using a flow-through cell	Field
pH**	E150.1/SW9040, direct-reading meter	Measure at well-head	Purging adequacy; aerobic and anaerobic processes are pH-sensitive	Each sampling event	Measure at well-head using a flow-through cell	Field
Conductivity**	E120.1/SW9050, direct-reading meter	Measure at well-head	General water quality parameter used as a marker to verify that site samples are obtained from the same groundwater system	Each sampling event	Collect 100–250 mL of water in a glass or plastic container or measure at wellhead using flow-through cell	Field
Nitrate (NO_3^{-1})	IC method E300 or method SW9056; colorimetric, method E353.2	Method E300 is a Handbook[a/] method; method SW9056 is an equivalent procedure	Substrate for microbial respiration if oxygen is depleted	Each sampling event	Collect up to 40 mL of water in a glass or plastic container; cool to 4°C; analyze within 48 hours	Fixed-base

TABLE 7.1 (Concluded)
LONG-TERM GROUNDWATER MONITORING ANALYTICAL PROTOCOL
OU4 RNA TS
SHAW AFB, SOUTH CAROLINA

Analyte	Method/Reference	Comments	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Field or Fixed-Base Laboratory
Sulfate (SO_4^{2-})	IC method E300 or method SW9056 or Hach SulfaVer 4 method	Method E300 is a Handbook method; method SW9056 is an equivalent procedure. Hach method is Photometric	Substrate for anaerobic microbial respiration	Each sampling event	Collect up to 40 mL of water in a glass or plastic container; cool to 4°C	Fixed-base or field (for Hach method)
Oxidation-Reduction Potential (ORP)**	A2580 B, direct-reading meter	Measurements are made with electrodes; results are displayed on a meter; samples should be protected from exposure to atmospheric oxygen	The redox potential of groundwater influences and is influenced by biologically mediated reactions; the redox potential of groundwater may range from more than 200 mV to less than -400 mV	Each sampling event	Measure at well-head using a flow-through cell	Field
Methane	RSKSOP-114 modified to analyze water samples for methane by headspace sampling with dual thermal conductivity and flame ionization detection.	Method published and used by the USEPA National Risk Management Research Laboratory	The presence of methane indicates the presence of sufficiently reducing conditions for reductive dehalogenation to occur	Each sampling event	Collect water samples in 40 mL volatile organic analysis (VOA) vials with butyl gray/Teflon-lined caps (zero headspace); cool to 4°C	Fixed-base
Aromatic Volatile Organics**	GC/MS method SW8260b or GC method SW8021b.	SW8260 is the Handbook method.	Measured for regulatory compliance.	Each sampling event	Collect water samples in a 40 mL VOA vial; cool to 4°C; add hydrochloric acid to pH < 2	Fixed-base

a/ Handbook refers to the AFCEE (1993) "Handbook for the Installation Restoration Program (IRP) Remedial Investigations and Feasibility Studies (RI/FS)."
Note: ** indicates parameters that should be monitored in both LTM and sentry wells; all other parameters should only be monitored in LTM wells.

SECTION 8

CONCLUSIONS AND RECOMMENDATIONS

This report presents the results of a TS conducted to evaluate the use of natural attenuation for remediation of CAH-contaminated groundwater at OU-4 at Shaw AFB, South Carolina. The finite-difference models MODFLOW and MT3D96® were used in conjunction with site-specific geologic, hydrologic, and laboratory analytical data to simulate the migration and biodegradation of CAHs dissolved in groundwater. To obtain the data necessary for the RNA demonstration, soil, groundwater, surface water, and sediment samples were collected from the site and analyzed. Physical and chemical data collected under this program were supplemented (where necessary) with data collected during previous site characterization events.

Comparison of CAH, TOC, electron acceptor, and byproduct data provides strong evidence that CAHs dissolved in groundwater at OU-4 are being naturally degraded. CAH compounds such as PCE, TCE, and 1,1,1-TCA are undergoing biologically facilitated (anaerobic) reductive dechlorination (e.g., TCE to DCE or 1,1,1-TCA to 1,1-DCA) and abiotic losses through dehydrohalogenation (e.g., 1,1,1-TCA to 1,1-DCE). The effects of these anaerobic processes, combined with physical dilution and chemical sorption, is causing the parent solvent concentrations at the site to decrease by approximately 2 orders-of-magnitude between the source area and Long Branch Creek. The anaerobic destruction of DCE and DCA (the byproducts of TCE and TCA dechlorination) also is likely occurring in the more anaerobic portion of the groundwater plume near the source area; however, DCE and DCA are reduced to a lesser extent between the source area and Long Branch Creek than observed with TCE and TCA. Near the leading edge of the plume near the creek, reductive dechlorination appears to be less prevalent, and compounds such as DCE, DCA, VC, and the chlorobenzenes likely are aerobically degraded or diluted. These compounds either were not detected or were detected at very low concentration in Long Branch Creek.

Site-specific hydrogeologic and laboratory analytical data were used in the numerical groundwater model to simulate the effects of advection, dispersion, sorption, and biodegradation on the fate and transport of the total dissolved CAH plume and the 1,1,1-TCA plume. A surrogate IM remedial groundwater standard for 1,1,1-TCA was defined by SCDHEC (1997), and this compound is used as an indicator compound in this report. Therefore, the fate and transport of 1,1,1-TCA was simulated using the numerical model. During model calibration, model parameters that could not be obtained from existing site data were estimated using common literature values for aquifer materials similar to those found at the site. Model predictions were found to be very sensitive to the magnitude of the first-order CAH decay rate assigned to the shallow portion of the surface aquifer at OU-4.

Remedial Alternative 1 incorporates natural attenuation, but does not include engineered remediation. The model used to simulate this alternative (OU4MODA) incorporates the assumption that dissolution from mobile and/or residual NAPL in the source area into groundwater will naturally decrease at a geometric rate of 3 percent per year (each concentration was decreased by a factor equal to 3 percent of the previous year's concentration) during the 100-year predictive period. The results of the model indicate that CAH concentrations will continue migrating from the source area to the edge of Long Branch Creek and are not predicted to decrease below the IM goal for 1,1,1-TCA (the surrogate compound for the site) of 1,000 µg/L for 95 years. CAH concentrations discharging to Long Branch Creek are significantly lower than source area concentrations, and appear to have a minimal impact on surface water quality based on the lack of 1,1,1-TCA detections in the creek.

Model OU4MODB, used to simulate remedial Alternative 2, assumes that partial source removal via application of an engineered remedial technology such as SVE would reduce total CAH and 1,1,1-TCA dissolution from NAPL within a 5-year operational period. This model incorporates the assumption that the SVE system will reduce the dissolution of CAH compounds into groundwater by 8 percent per year for the first 2 years, 5 percent per year for the next 3 years, and 3 percent per year for the remainder of the 100 year model simulation. Results of these models indicate that source reduction at the assumed rates would result in only marginal decreases in dissolved CAH and 1,1,1-TCA concentrations within the plume relative to Alternative 1. Model OU4MODB predicts that leachable CAH contamination will be reduced by approximately 12 percent by calendar year 2008 (5 years of SVE followed by 5 years of natural weathering) over OU4MODA simulations and that 1,1,1-TCA concentrations will decrease below 1,000 µg/L within approximately 90 years.

A third groundwater model was used to simulate the potential effects of a groundwater extraction and treatment system at the site. Model OU4MODC was identical to OU4MODA, except that it used a single pumping well placed in the currently delineated 1,1,1-TCA plume source, near monitoring point MPC. The results of this model indicate that groundwater extraction and treatment at rates above 20 gpm will likely mitigate any contact of the 1,1,1-TCA plume lobe with Long Branch Creek. However, long-term groundwater extraction and treatment is not the recommended remedial method for the site. The permeable reactive barrier wall installed in November 1998 is preferable to groundwater extraction and treatment and may degrade groundwater contaminants before entry into Long Branch Creek. Future groundwater sampling will determine the effectiveness of the barrier wall and if LTM period or sampling frequency can be modified. Any groundwater treatment or interception system would potentially continue indefinitely unless the source area were remediated simultaneously. Furthermore, groundwater extraction and treatment would alter the hydraulic and geochemical characteristics of the site, thereby affecting contaminant decay rates and preventing the collection of meaningful data for monitored natural attenuation.

On the basis of this evaluation, Alternative 2, which combines natural attenuation with NAPL source removal through SVE, is recommended. Implementation of Alternative 2 will reduce the overall remediation time. A properly designed SVE system may achieve removal rates greater than assumed in the model simulations, further accelerating remediation rates at OU-4. Prior to installation of the SVE system,

the performance of a minimally intrusive soil gas survey should be considered to pinpoint subsurface CAH and 1,1,1-TCA "hot spots." A simple active or passive soil-gas survey would aid in identifying the location of mobile or residual LNAPL, thereby refining the design and effectiveness of any engineered remediation system.

The beneficial effects of natural attenuation are included in Alternative 2. Available data indicate that the total CAH and 1,1,1-TCA plumes are stabilized and biodegrading east of the source area. The degree to which RNA will continue to prevent significant downgradient migration of the plume is not known with certainty, but will become more apparent as successive LTM sampling events are performed. In any event, model results suggest that the drinking water criterion and aquatic life standard for 1,1,1-TCA will not be exceeded in Long Branch Creek at any time in the future; this observation is supported by the lack of quantifiable 1,1,1-TCA detections in Long Branch Creek. Shallow groundwater at the site or surface water in Long Branch Creek are not being used as a drinking water or irrigation source, and may not represent a viable potable water source due to the proximity and restricted nature of the base.

To assess the effectiveness of both naturally-occurring processes and SVE at reducing contaminant mass and minimizing contaminant migration, groundwater from a minimum of 8 existing monitoring wells and 4 proposed monitoring wells should be sampled annually for 5 years to build a historical groundwater quality database for the site. Six surface water stations also should be sampled annually during this 5-year period. Following completion of the 5-year annual LTM period, the LTM program should be reassessed. If the annual sampling results indicate that temporal changes in plume magnitude and extent could be adequately monitored by less-frequent sampling events, then the frequency of LTM could be reduced appropriately. The number and location of wells and surface water stations selected for continued monitoring should be determined on the basis of results from the initial, 5-year LTM period.

The LTM plan should be periodically reviewed and revised as appropriate on the basis of available groundwater quality data. For example, if sampling results demonstrate that the plume is in equilibrium (not receding or migrating downgradient) or is receding toward the source area, then the sampling frequency could be reduced appropriately. If the data collected at any time during the monitoring period indicate the need for additional remedial activities at the site, sampling frequency should be adjusted accordingly and the appropriate remedial actions (e.g., air sparging, iron filing trench as briefly described in Section 6.2.4) should be evaluated and implemented.

SECTION 9

REFERENCES

Abriola, L.M., 1996, Organic liquid contaminant entrapment and persistence in the subsurface: Interphase mass transfer limitation and implications for remediation. 1996 Darcy Lecture, National Ground Water Association, presented at Colorado School of Mines, October 25, 1996.

Altenschmidt, U. and Fuchs, G., 1991, Anaerobic degradation of toluene in denitrifying Pseudomonas sp.: Indication for toluene methylhydroxylation and benzoyl-CoA as central aromatic intermediate: Arch. Microbial., vol. 156, p. 152-158.

Alvarez-Cohen, L.M. and McCarty, P.L., 1991a, Effects of toxicity, aeration, and reductant supply on trichloroethylene transformation by a mixed methanotrophic culture. *Appl. Environ. Microbiol.*, 57(1):228-235.

Alvarez-Cohen, L.M. and McCarty, P.L., 1991b, Product toxicity and cometabolic competitive inhibition modeling of chloroform and trichloroethylene transformation by methanotrophic resting cells. *Appl. Environ. Microbiol.*, 57(4):1031-1037.

Alvarez, P.J.J., and Vogel, T.M., 1991, Substrate interactions of benzene, toluene, and para-xylene during microbial degradation by pure cultures and mixed culture aquifer slurries: Applied Environmental Microbiology, vol. 57, p. 2981-2985.

Arciero, D., Vannelli, T., Logan, M., and Hooper, A.B., 1989, Degradation of trichloroethylene by the ammonia-oxidizing bacterium *Nitrosomonas europaea. Biochem. Biophys. Res. Commun.*, 159:640-643.

Ashworth, R.A., Howe, G.B., Mullins, M.E., and Rogers, T.N., 1988, Air-water partitioning coefficients of organics in dilute aqueous solutions. *Journal of Hazardous Materials*, 18:25-36.

Atlas, R.M., 1981, Microbial degradation of petroleum hydrocarbons - an environmental perspective: Microbiological Reviews, vol. 45, no. 1, p. 180-209.

Atlas, R.M., 1984, Petroleum Microbiology: Macmillan Publishing Company, New York.

Atlas, R.M., 1988, Microbiology - Fundamentals and Applications: Macmillan Publishing Company, New York.

Baedecker, M.J., Siegel, D.I., Bennett, P.C., Cozzarelli, I.M., 1988, The fate and effects of crude oil in a shallow aquifer: I. The distribution of chemical species

and geochemical facies, In: G.E. Mallard, and S.E. Ragone, editors, U.S. Geological Survey Toxic Substances Hydrology Program, Proceedings of the Technical Meeting, Phoenix, Arizona, September 26-30, 1988: U.S. Geological Survey Water-Resources Investigations Report 88-42320, p. 29-22.

Baedecker, M.J., and Cozzarelli, I.M., 1991, Geochemical modeling of organic degradation reactions in an Aquifer contaminated with Crude Oil: U.S. Geological Survey Water-Resources Investigations Report 91-4034. Reston, VA. p 627-632.

Ball, H.A., Reinhard, M., and McCarty, P.L., 1991, Biotransformation of monoaromatic hydrocarbons under anoxic conditions, In: In Situ Bioreclamation, Applications and Investigations for Hydrocarbon and Contaminated Site Remediation. Eds. R.E. Hinchee and R.F. Olfenbuttel. Butterworth-Heinemann. Boston, MA. p. 458-463.

Barker, J.F., Patrick, G.C., and Major, D., 1987, Natural attenuation of aromatic hydrocarbons in a shallow sand aquifer: Ground Water Monitoring Review, Winter, 1987, p. 64-71.

Bartha, R., 1986, Biotechnology of petroleum pollutant biodegradation: Microbial Ecology, vol. 12, p. 155-172.

Bauman, B., 1991, Biodegradation research of the American Petroleum Institute. Presented at: In Situ Bioreclamation: Application and Investigation for Hydrocarbons and Contaminated Site Remediation. San Diego, CA. March 19-21, 1991.

Bear, J., 1979, *Hydraulics of Groundwater.* McGraw-Hill International Book Co., New York.

Beller, H.R. Reinhard, M., and Grbic-Galic, D., 1992, Metabolic byproducts of anaerobic toluene degradation by sulfate-reducing enrichment cultures: Appl. Environ. Microbiol., vol. 58, p. 3192-3195.

Borden, R.C., 1991, Simulation of enhanced in situ biorestoration of petroleum hydrocarbons. In: In Situ bioreclamation: Application and Investigation for Hydrocarbons and contaminated Site Remediation. Eds., R.E. Hinchee and R. F. Olfenbuttel. Butterworth-Heinemann. p. 529-534.

Bouwer, E.J., 1992, Bioremediation of Subsurface Contaminants. In: Mitchell, R.(ed.), *Environmental Microbiology*. Wiley-Liss, New York.

Bouwer, E.J., 1994, Bioremediation of chlorinated solvents using alternate electron acceptors. In: Norris, R.D., Hinchee, R.E., Brown, R., McCarty, P.L., Semprini, L., Wilson, J.T., Kampbell, D.H., Reinhard, M., Bouwer, E.J., Borden, R.C., Vogel, T.M., Thomas, J.M., and Ward, C.H. (eds.), *Handbook of Bioremediation.* Lewis Publishers.

Bouwer, E.J., Rittman, B.E., and McCarty, P.L., 1981, Anaerobic degradation of halogenated 1- and 2-carbon organic compounds. *Environ. Sci. Technol.*, 15(5):596-599.

Bouwer, E.J. and Wright, J.P., 1988, Transformations of trace halogenated aliphatics in anoxic biofilm columns. *J. Contam. Hydrol.*, 2:155-169.

Bouwer, H., 1989, The Bouwer and Rice slug test - an update. *Ground Water*, 27(3):304-309.

Bouwer, H. and Rice, R.C., 1976, A slug test for determining hydraulic conductivity of unconfined aquifers with completely or partially penetrating wells. *Water Resources Research*, 12(3):423-428.

Bradley, P.M. and Chapelle, F.H., 1996, Anaerobic mineralization of vinyl chloride in Fe(III)-reducing aquifer sediments. Accepted for publication in: *Environmental Science and Technology.*

Brown, R.A., Dey, J.C. and McFarland, W.E., 1991, Integrated site remediation combining groundwater treatment, soil vapor extraction, and bioremediation, In: In Situ Bioreclamation: Application and Investigation for Hydrocarbons and Contaminated Site Remediation. Eds., R.E. Hinchee and R. F. Olfenbuttel. Butterworth-Heinemann. p. 444-449.

Buscheck, T.E. and Alcantar, C.M., 1995, Regression techniques and analytical solutions to demonstrate intrinsic bioremediation. In: *Proceedings of the 1995 Battelle International Conference on In-Situ and On Site Bioreclamation*. April.

Butler, B.J., and Barker, J.F., 1996, Chemical and microbiological transformation and degradation of chlorinated solvent compounds, In, Pankow, J.F., and Cherry, J.A., eds., Dense Chlorinated Solvents and Other DNAPLs in Groundwater: History, Behavior, and Remediation: Waterloo Press, Waterloo, Ontario, p. 267-312.

Chapelle, F.H., 1993, *Ground-Water Microbiology and Geochemistry*. John Wiley & Sons, Inc., New York.

Chapelle, F.H., McMahon, P.B., Dubrovsky, N.M., Fujii, R.F., Oaksford, E.T., and Vroblesky, D.A., 1995, Deducing the distribution of terminal electron-accepting processes in hydrologically diverse groundwater systems. *Water Resources Research*, 31:359-371.

Chiang, C.Y., Salanitro, H.P., Chai, E.Y., Colthart, H.D., and Klein, C.L., 1989, Aerobic biodegradation of benzene, toluene, and xylene in a sandy aquifer - data analysis and computer modeling: Ground Water, vol. 27, no. 6, p. 823-834.

Cline, P.V. and Delfino, J.J., 1989, Transformation kinetics of 1,1,1-trichloroethane to the stable product 1,1-dichloroethene. In: *Biohazards of Drinking Water Treatment*. Lewis Publishers, Inc, Chelsea, MI.

Cohen, R. M., and J. W. Mercer, 1993, *DNAPL Site Evaluation*. CRC Press, Inc., Boca Raton, Florida.

Cozzarelli, I.M., Eganhouse, R.P., and Baedecker, M.J., 1990, Transformation of monoaromatic hydrocarbons to organic acids in anoxic ground water environment: Environmental and Geological Water Science, vol. 16.

Criddle, C.S., J.T. DeWitt, and P.L. McCarty, 1990, Reductive dehalogenation of carbon tetrachloride by Escherichia coli K-12. Applied and Environmental Microbiology, 56:3247-3254.

Davis, J.W. and Carpenter, C.L., 1990, Aerobic biodegradation of vinyl chloride in groundwater samples. *Applied and Environmental Microbiology*, 56:3878.

Davis, J.W., Klier, N.J., and Carpenter, 1994, Natural biological attenuation of benzene in ground water beneath a manufacturing facility: Ground Water, vol. 32, no. 2, p. 215-226.

de Bont, J.A.M., Vorage, M.J.W., Hartmans, S., and van den Tweel, W.J.J., 1986, Microbial degradation of 1,3-dichlorobenzene: Applied and Environmental Microbiology, v. 52, p. 677-680.

De Bruin, W.P., Kotterman, M.J.J., Posthumus, M.A., Schraa, G., and Zehnder, A.J.B., 1992, Complete biological reductive transformation of tetrachloroethene to ethane: Applied and Environmental Microbiology, v. 58, no. 6, p. 1966 - 2000.

DeStefano, T.D., Gossett, J.M., and Zinder, S.H., 1991, Reductive dehalogenation of high concentrations of tetrachloroethene to ethene by an anaerobic enrichment culture in the absence of methanogenesis. *Appl. Environ. Microbiol.*, 57(8):2287-2292.

Dewulf, J., Drijvers, D., and Van Langenhove, H., 1995, Measurement of Henry's law constant as function of temperature and salinity for the low temperature range. *Atmos. Environ.*, 29(3):323-331.

Domenico, P.A., and Schwartz, F.W., 1990, Physical and Chemical Hydrogeology. John Wiley and Sons, New York, New York, 824p.

Edwards, E., Wills, L.E., Grbic-Galic, D., and Reinhard, M., 1991, Anaerobic degradation of toluene and xylene--evidence for sulfate as the terminal electron acceptor, In: In Situ Bioreclamation, Applications and Investigations for Hydrocarbon and Contaminated Site Remediation. Eds. R.E. Hinchee and R.F. Olfenbuttel. Butterworth-Heinemann. Boston, MA. p. 463-471.

Edwards, E.A., and Grbic-Galic, D., 1992, Complete mineralization of benzene by aquifer microorganisms under strictly anaerobic conditions: Applied and Environmental Microbiology, vol. 58, p. 2663-2666.

Edwards, E.A., and Grbic-Galic, D., 1994, Anaerobic degradation of toluene and o-xylene by a methanogenic consortium. Applied and Environmental Microbiology, v.60, p313-322.

Engineering-Science, Inc., 1983, Installation Restoration Program, Phase I: Records Search, Shaw AFB, South Carolina.

Feenstra, S. and Guiguer, N., 1996, Dissolution of dense non-aqueous phase liquids in the subsurface. In: Pankow, J.F., and Cherry, J.A. (eds.), *Dense Chlorinated Solvents And Other DNAPLS In Groundwater*. Waterloo Press, Portland, OR.

Florida Department of Environmental Protection (FDEP), 1993, Primary and Secondary Drinking Water Standards, Orlando, Florida.

Focht, R., Vogan, J., and S. O'Hannersin, 1996, Field application of reactive iron walls for *in-situ* degradation of volatile organic compounds in groundwater. *Remediation*, Summer, John Wiley & Sons, Inc.

Folsom, B.R., Chapman, P.J., and Pritchard, P.H., 1990, Phenol and trichloroethylene degradation by *Pseudomonsa cepacia* G4: Kinetics and interactions between substrates. *Appl. Environ. Microbiol.*, 56(5):1279-1285.

Franke, O.L., Reilly, T.E., and Bennett, G.D., 1987, Definition of boundary and initial conditions in the analysis of saturated ground-water flow systems - an introduction. In: *United States Geological Survey Techniques of Water-Resources Investigations,* Book 3, Chapter B5.

Freedman, D.L. and Gossett, J.M., 1989, Biological reductive dehalogenation of tetrachloroethylene and trichloroethylene to ethylene under methanogenic conditions. *Appl. Environ. Microbiol.*, 55(4):1009-1014.

Geraghty & Miller Modeling Group, 1994, AQTESOLV Aquifer Test Solver, Version 2.0. Millersville, Maryland. October.

Gibson, D.T., and Subramanian, V., 1984, Microbial degradation of aromatic hydrocarbons, In: Gibson, D.T., ed: Microbial Degradation of Organic Compounds, Marcel Dekker, Inc., p. 181-252.

Godsey, E.M., 1994, Microbiological and geochemical degradation processes. *Symposium on Intrinsic Bioremediation in Ground Water,* Denver, CO. August 30 - September 1.

Goldstein, R.M., Mallory, L.M., and Alexander, M., 1985, Reasons for Possible Failure of Inoculation to Enhance Biodegradation: Applied Environmental Microbiology, vol. 50, no. 4, p. 977-983.

Grbic´-Galic´, D., 1990, Anaerobic microbial transformation of nonoxygenated aromatic and alicyclic compounds in soil, subsurface, and freshwater sediments. In: Bollag, J.M. and Stotzky, G.(eds.), *Soil Biochemistry.* Marcel Dekker, Inc., New York.

Haag, F., Reinhard, M., and McCarty, P.L., 1991, Degradation of toluene and p-xylene in an anaerobic microcosms: Evidence for sulfate as a terminal electron acceptor: Environ. Toxicol. Chem., vol. 10, p. 1379-1389.

Haigler, B.E., Nishino, S.F., and Spain, J.C., 1988, Degradation of 1,2-dichlorobenzene by a *Pseudomonas sp.*: Applied and Environmental Microbiology, v. 54, p. 294-301.

Harker, A.R. and Kim, Y., 1990, Trichloroethylene degradation by two independent aromatic-degrading pathways in *Alcaligenes eutrophus* JMP134. *Appl. Environ. Microbiol.*, 56(4):1179-1181.

Hartmans, S. and de Bont, J.A.M., 1992, Aerobic vinyl chloride metabolism in *Mycobacterium aurum Li. Appl. Environ. Microbiol.*, 58(4):1220-1226.

Henry, S.M., 1991, *Transformation of trichloroethylene by methanotrophs from a groundwater aquifer*. Ph.D. Thesis, Stanford University. Palo Alto, California.

Hine, J., and Mookerjee, P.K., 1975, The Intrinsic Hydrophilic Character of Organic Compounds. Correlations in Terms of Structural Contributions: Journal or Organic Chemistry, 40(3):292-298.

Hunter-Smith, R.J., Balls, P.W., and P.S. Liss, 1983, Henry's Law Constants and the Air-Sea Exchange of Various Low Molecular Weight Halocarbon Gases. *Tellus*, 35B:170-176.

Hutchins, S.R., and Wilson, J.T., 1991, Laboratory and field studies on BTEX biodegradation in a fuel-contaminated aquifer under denitrifying conditions, In: In Situ Bioreclamation, Applications and Investigations for Hydrocarbon and Contaminated Site Remediation. Eds. R.E. Hinchee and R.F. Olfenbuttel. Butterworth-Heinemann. Boston, MA. p. 157-172.

Hutchins, S.R., Sewell, G.W., Sewell, D.A., Kovacs, D.A., and Smith, G.A., 1991a, Biodegradation of monoaromatic hydrocarbons by aquifer microorganisms using oxygen, nitrate, or nitrous oxide as the terminal electron acceptor: Environ. Sci. Technol., vol. 25, no. 1, p. 68-76.

Hutchins, S.R., Downs, W.C., Smith, G.B., Smith, J.T., Wilson, D.J., Hendrix, D.J., Fine, D.D., Kovacs, D.A., Douglass, R.H., and Blaha, F.A., 1991b, Nitrate for Biorestoration of an Aquifer Contaminated with Jet Fuel. U.S. Environmental Protection Agency. Robert S. Kerr Environmental Research Laboratory. Ada, Oklahoma. EPA/600/2-91/009. April, 1991.

Jamison, V.W., Raymond, R.L., and Hudson, J.O. Jr., 1975, Biodegradation of high-octane gasoline in ground water: Developments in Industrial Microbiology, vol. 16.

Jeffers, P.M., Ward, L.M., Woytowitch, L.M., and Wolfe, N.L., 1989, Homogeneous hydrolysis rate constants for selected chlorinated methanes, ethanes, ethenes, and propanes: Environmental Science and Technology, v. 23, p. 965-969.

IT Corporation, 1997, Draft Chemical Oxidation Pilot Test Report, Operable Unit 4, IRP Site Number FT-01, Shaw AFB, SC, Contract No. DACW 45-93-D-0044, TERC Region 2, Delivery Order 0004, AF Project No. VLSB-95-7002, February, 1997.

Klier, N.J., Welt, R.J., and Donberg, P.A., 1996, Aerobic biodegradation of dichlorethylenes in surface and subsurface soils. Submitted to *Chemosphere* by The Dow Chemical Company, Environmental Toxicology and Chemistry Laboratory, Health and Environmental Sciences. May.

Konikow, L.F., and Bredehoeft, J.D., 1978, Computer model of two-dimensional solute transport and dispersion in groundwater. *United States Geological Survey, Techniques of Water Resources Investigations of the United States Geological Survey*, Book 7, Chapter C2, 90 p.

Kuehne, D., and Buscheck, T., 1996, Survey of California marketing sites and analysis of monitoring well data: Chevron Research and Technology, unpublished report.

Law Environmental, Inc., 1989, Remedial Action Plan, Shaw Air Force Base, July.

Law Environmental, Inc., 1991, Draft Remedial Investigation and Feasibility Study Report for Site 1 - Former Fire Training Area No. 1, Shaw AFB, Sumter, SC. Prepared for the US Army Corps of Engineers-Omaha Divisions, Decrease. December.

Leahy, J.G., and Colewell, R.R., 1990, Microbial degradation of hydrocarbons in the environment: Microbiolgical Reviews, vol. 53, no. 3, p. 305-315.

Lee, M.D., 1988, Biorestoration of Aquifers Contaminated with Organic Compounds: CRC Critical Reviews in Environmental Control. vol. 18. p. 29-89.

Little, C.D., Palumbo, A.V., Herbes, S.E., Lidstrom, M.E., Tyndall, R.L., and Gilmer, P.J., 1988, Trichloroethylene biodegradation by a methane-oxidizing bacterium. *Appl. Environ. Microbiol.*, 54(4):951-956.

Lovley, D.R., Chapelle, F.H., and Woodward, J.C., 1994, Use of dissolved H_2 concentrations to determine distribution of microbially catalyzed redox reactions in anoxic groundwater. *Environmental Science and Technology*, 28(7):1205-1210.

Lovley, D.R. and Goodwin, S., 1988, Hydrogen concentrations as an indicator of the predominant terminal electron-accepting reaction in aquatic sediments. *Geochimica et Cosmochimica Acta*, 52:2993-3003.

Lovely, D.R. and Phillips, E.J.P., 1988. Novel mode of microbial energy metabolism: Organic carbon oxidation coupled to dissimilatory reduction of iron or manganese. *Applied and Environmental Microbiology*, 54(6):1472-1480.

Lovely, D.R. and Phillips, E.J.P., 1991, Enzymatic versus nonenzymatic mechanisms for Fe(III) reduction in aquatic sediments. *Environmental Science and Technology*, 26(6):1062-1067.

Lyman, W.J., Reidy, P.J., and Levy, B., 1992, Mobility and Degradation of Organic Contaminants in Subsurface Environments. C.K. Smoley, Inc., Chelsea, MI.

Mace, R.E., Fisher, R.S., Welch, D.M., and Parra, S.P., 1997, Extent, Mass, and Duration of Hydrocarbon Plumes from Leaking Petroleum Storage Tank Sites in Texas: Texas Bureau of Economic Geology, Geological Circular 97-1.

Malone, D.R., Kao, C.M., and Borden, R.C., 1993, Dissolution and biorestoration of nonaqueous phase hydrocarbons - models development and laboratory evaluation: Water Resources Research, vol. 29, no. 7, p. 2003-2213.

Mayer, K.P., Grbic-Galic, D., Semprini, L., and McCarty, P.L., 1988, Degradation of trichloroethylene by methanotrophic bacteria in a laboratory column of saturated aquifer material. *Wat. Sci. Tech.* (Great Britain), 20(11/12):175-178.

McCarty, P.L., Roberts, P.V., Reinhard, M., and Hopkins, G., 1992, Movement and transformations of halogenated aliphatic compounds in natural systems. In: Schnoor, J.L. (Ed.), *Fate of Pesticides and Chemicals in the Environment*. John Wiley & Sons, Inc., New York, New York.

McCarty, P.L. and Semprini, L., 1994, Ground-water treatment for chlorinated solvents. In: *Handbook of Bioremediation*. Lewis Publishers, Boca Raton, FL.

McDonald, G. and Harbaugh, A.W., 1988, A modular three-dimensional finite-difference groundwater flow model. *US Geological Survey Techniques of Water Resources Investigations*, Book 6, Chapter A1.

Miller, R.E. and Guengerich, F.P., 1982, Oxidation of trichloroethylene by liver microsomal cytochrome P-450: Evidence for chlorine migration in a transition state not involving trichloroethylene oxide. *Biochemistry*, 21:1090-1097.

Montgomery, J.J. 1996. Groundwater Chemicals Desk Reference. Lewis Publishers, Boca Raton.

Moutoux, D.E., Benson, L.A., Swanson, T.H., Wiedemeier, T.H., Lenhart, J., Wilson, J.T., and Hansen J.E., 1996, Estimating the changing rate of anaerobic reductive dechlorination of chlorinated aliphatic hydrocarbons in the presence of petroleum hydrocarbons. *In: Proceedings of the 1996 API/NGWA Conference on Petroleum Hydrocarbons and Organic Chemicals in Ground Water*. Houston, Texas. November.

Murray, W.D. and Richardson, M., 1993, Progress toward the biological treatment of C_1 and C_2 halogenated hydrocarbons. *Critical Reviews in Environmental Science and Technology*, 23(3):195-217.

Neely, W.B., and G.e. Blau, 1985, *Environmental Exposure from Chemicals. Volume 1*, CRC Press, Inc., Boca Raton, Florida.

Nelson, M.J.K., Montgomery, S.O., O'Neille, E.J., and Pritchard, P.H., 1986, Aerobic metabolism of trichloroethylene by a bacterial isolate. *Appl. Environ. Microbiol.*, 52(2):949-954.

Nishino, S.F., Spain, J.C., and Pettigrew, C.A., 1994, Biodegradation of chlorobenzene by indigeneous bacteria: Environ. Toxicol. Chem., v. 13, p. 871-877.

Papadoulos, S.S., and Assoc., 1996, *MT3D96: A Modular Three-Dimensional Transport Model for Simulation of Advection, Dispersion, and Chemical Reactions of Contaminants in Ground-Water Systems*. Bethesda, Maryland.

Parsons ES, 1994, Bioventing Test Work Plan For IRP Site FT-01 (Former Fire Training Area 1) and IRP Site SS-15 (POL Fuel Depot), Shaw AFB. May.

Parsons ES, 1995, Draft Interim Bioventing Pilot Tests Results Report: IRP Site FT-01 (Former Fire Training Area 1) and IRP Site SS-15 (POL Fuel Depot), Shaw AFB, SC. January.

Parsons ES, 1996, Memorandum to Mr. Rick Roller Re: Completion of Final Bioventing Test, Shaw AFB, Site FT-01 (Former Fire Training Area 1) and Site SS-15 (POL Fuel Depot). April.

Parsons ES, 1997. Draft Work Plan for a Treatability Study in Support of Remediation by Natural Attenuation of Sites OU-4 (FT-1) and the Building 1613 Site.

Reineke, W., and Knackmuss, H.-J., 1984, Microbial metabolism of haloaromatics: Isolation and properties of a chlorobenzene-degrading bacterium: European Journal of Applied Micriobiology and Biotechnology, v. 47, p. 395-402.

Reinhard, M., 1994, In-Situ bioremediation technologies for petroleum-derived hydrocarbons based on alternate electron acceptors (other than molecular oxygen). *Handbook of Bioremediation*. Lewis Publishers, Boca Raton, FL.

Research Triangle Institute, 1986, Installation Restoration Program: Phase II: Confirmation 1 Quantification Stage 1, Shaw AFB, South Carolina, January.

Rice, D.W., Grose, R.D., Michaelsen, J.C., Dooher, B.P. , MacQueen, D.H., Cullen, S.J., Kastenberg, W.E., Everett, L.G., and Marino, M.A., 1995, California Leaking Underground Fuel Tank (LUFT) Historical Case Analyses: Environmental Protection Department, Environmental Restoration Division, Lawrence Berkely laboratories, UCRL-122207, prepared for the California State Water Resources Control Board.

Rust E&I, 1993, Soil Vapor Extraction and Bioremediation Study Report, Operable Unit #4, Former Fire Training Area No. 1, Shaw AFB, SC. June.

Rust E&I, 1994, Draft Final Site Inspection Report, Multi-Sites Group II, Shaw AFB, SC. January.

Rust E&I, 1995, Final Remedial Investigation: Operable Unit #4, Former Fire Training Area No. 1 IRP Site No. FT-1, Shaw AFB, SC. February.

Rust E&I, 1996, Final Feasibility Study/Corrective Measures Study Report, Proposal Plan, Operable Unit #4, Former Fire Training Area #1, IRP Site No. FT-1, SWMU #59.

Sander, P., Wittaich, R.-M., Fortnagel, P., Wilkes, H., and Francke, W., 1991, Degradation of 1,2,4-trichloro- and 1,2,4,5-tetrachlorobenzene by *Pseudomonas* strains: Applied and Environmental Microbiology, v. 57, p. 1430-1440.

Schraa, G., Boone, M.L., Jetten, M.S.M., van Neerven, A.R.W., Colberg, P.J., and Zehnder, A.J.B., 1986, Degradation of 1,2-dichlorobenzene by *Alcaligenes sp.* strain A175: Applied and Environmental Microbiology, v. 52, p. 1374-1381.

SEC Donohue, Inc., 1992, Final Supplemental Remedial Investigation/Feasibility Study Work Plan: Operable Unit #4, Former Fire Training Area No. 1, Shaw Air Force Base, Sumpter, South Carolina.

South Carolina Department of Health and Environmental Control (SCDHEC), July 14, 1997, Interim Measure (IM) letter to Mr. Randy Adams, 20 CES/CEV at Shaw AFB. Written by Mr. John T. Litton, Director, South Carolina DHEC, Division

of Hazasrdous and Infectious Waste Management, Bureau of Land and Waste Management.

Spain, J.C., 1996, Future vision: Compounds with potential for natural attenuation, In Proceedings of the Symposium on Natural Attenuation of Chlorinated Organics in Ground Water: EPA /540/R-96/509, Dallas TX, September 11-13, 1996.

Spain, J., 1997, Personal communication between Jim Spain of the US Air Force Armstrong Laboratory and Matt Swanson of Parsons ES regarding potential anaerobic utilization of chlorobenzenes as substrates. March 7, 1997.

Spain, J.C., and Nishino, S.F., 1987, Degradation of 1,4-dichlorobenzene by a *Pseudomonas sp.*: Applied and Environmental Microbiology, v. 53, p. 1010-1019.

Spitz, K. and Moreno, J., 1996, *A Practical Guide to Groundwater and Solute Transport Modeling*. John Wiley & Sons, Inc., New York, 461 p.

Stumm, W. and Morgan, J.J., 1981, *Aquatic Chemistry*. John Wiley & Sons, New York.

Strack, O.D.L., 1989, Groundwater Mechanics: Prentice-Hall, Englewood Cliffs, New Jersey, 732 p.

Suflita, J.M., and Townsend, G.T., 1995, The microbial ecology and physiology of aryl dehalogenation reactions and implications for bioremediation, In Young, L.Y., and Cerniglia, C.E., eds., Microbial Transformation andDegradation of Toxic Organic Chemicals: Wiley-Liss, New York, 654 p.

Thierrin, J., Davis, G.B., Barber, C., Patterson, B.M., Pribac, F., Power, T.R., and Lambert, M., 1992, Natural degradation rates of BTEX compounds and naphthalene in a sulfate-reducing ground water environment, In: In-Situ Bioremediation Symposium "92". Niagara-on-the-Lake, Ontario, Canada. September 20-24, 1992: In Press.

US Environmental Protection Agency (USEPA), 1988, Guidance for Conducting Remedial Investigations and Feasibility Studies (RI/FS) Under CERCLA. OSWER Directive 9355.3-01.

USEPA, 1991, Water Quality Criteria Summary Concentrations, Office of Science and Technology, Health and Ecological Criteria Division, Ecological Risk Assessment Branch (WH-585), Human Risk Assessment Branch (WH-550D), Washington, D.C.

USEPA, 1993, Revisions to the OMB Circular A-94 on Guidelines and Discount Rates for Benefit Cost Analysis, OSWER Directive 9355.3-20, June.

van der Meer, J.R., Roelofsen, W., Schraa, G., and Zehnder, A.J.B., 1987, Degradation of low concentrations of dichlorobenzenes and 1,2,4-trichlorobenzene by *Pseudomonas* sp. strain P51 in nonsterile soil columns: FEMS Microbiology Letters, v. 45, p. 333-341.

Vogel, T.M., 1994, Natural bioremediation of chlorinated solvents. In: *Handbook of Bioremediation*. Lewis Publishers, Boca Raton, FL.

Vogel, T.M., Criddle, C.S., and McCarty, P. L., 1987, Transformations of halogenated aliphatic compounds. *Environmental Science and Technology*, 21(8):722-736.

Vogel, T.M. and McCarty, P.L., 1985, Biotransformation of tetrachloroethylene to trichloroethylene, dichloroethylene, vinyl chloride, and carbon dioxide under methanogenic conditions. *Applied Environmental Microbiology*, 49(5):1080-1083.

Vogel, T.M., Criddle, C.S., and McCarty, P.L., 1987, Transformations of halogenated aliphatic compounds: Environmental Science and Technology, vol. 21, no. 8, p. 722 - 736.

Vroblesky, D.A., and Chapelle, F.H., 1994, Temporal and spatial changes of terminal electron-accepting processes in a petroleum hydrocarbon-contaminated aquifer and the significance for contaminant biodegradation: Water Resources Research, v. 30, no. 5, p. 1561-1570.

Waterloo Hydrogeologic Software, 1996, Visual MODFLOW, Version 2.20. Waterloo, Ontario, Canada.

Wiedemeier, T.H., Wilson, J.T., Kampbell, D.H., Miller, R.N., and Hansen, J.E., 1995, *Technical Protocol For Implementing Intrinsic Remediation With Long-Term Monitoring For Natural Attenuation Of Fuel Contamination Dissolved In Groundwater*. US Air Force Center for Environmental Excellence, San Antonio, Texas.

Wiedemeier, T.H., Benson, L.A., Wilson, J.T., Kampbell, D.H., Hansen, J.E., and Miknis, R., 1996a, Patterns Of Natural Attenuation Of Chlorinated Aliphatic Hydrocarbons At Plattsburgh Air Force Base, New York. In: *Conference on Intrinsic Remediation of Chlorinated Solvents*. Salt Lake City, UT. April 2.

Wiedemeier, T.H., Swanson, M.A., Moutoux, D.E., Gordon, E.K., Hansen, J.E., Haas, P., Wilson J.T., Kampbell, D.H., and Chapelle, F.H., 1996b, DRAFT *Protocol for Evaluating Natural Attenuation of Chlorinated Solvents in Groundwater*. Prepared for the Air Force Center for Environmental Excellence, Brooks Air Force Base, Texas. Revision 1.

Wilson, J.T. and Wilson, B.H., 1985, Biotransformation of trichloroethylene in soil. *Appl. Environ. Microbiol.*, 49(1):242-243.

Wilson, B.H., Smith, G.B., and Rees, J.F., 1986, Biotransformations of Selected Alkylbenzenes and Halogenated Aliphatic Hydrocarbons in Methanogenic Aquifer Material: A Microcosm Study: Environmental Science and Technology, 20(10):997-1002.

Wilson, B.H., Bledsoe, B., and Kampbell, D., 1987, Biological processes occurring at an aviation gasoline spill site, In: R.C. Averett and D.M. McKnight editors, Chemical Quality of Water and the Hydrologic Cycle. Lewis Publishers, Chelsea, Michigan, p.125-137.

Wilson, B.H., Wilson, J.T., Kampbell, D.H., Bledsoe, B.E., and Armstrong, J.M., 1990, Biotransformation of Monoaromatic and Chlorinated Hydrocarbons at an Aviation Gasoline Spill Site: Geomicrobiology Journal, 8:225-240.

Wilson, J.T., 1996, Personal communication between John Wilson of the USEPA NRMRL and Todd Wiedemeier of Parsons ES regarding USEPA definition of the term "natural attenuation", citing USEPA guidance undergoing internal review.

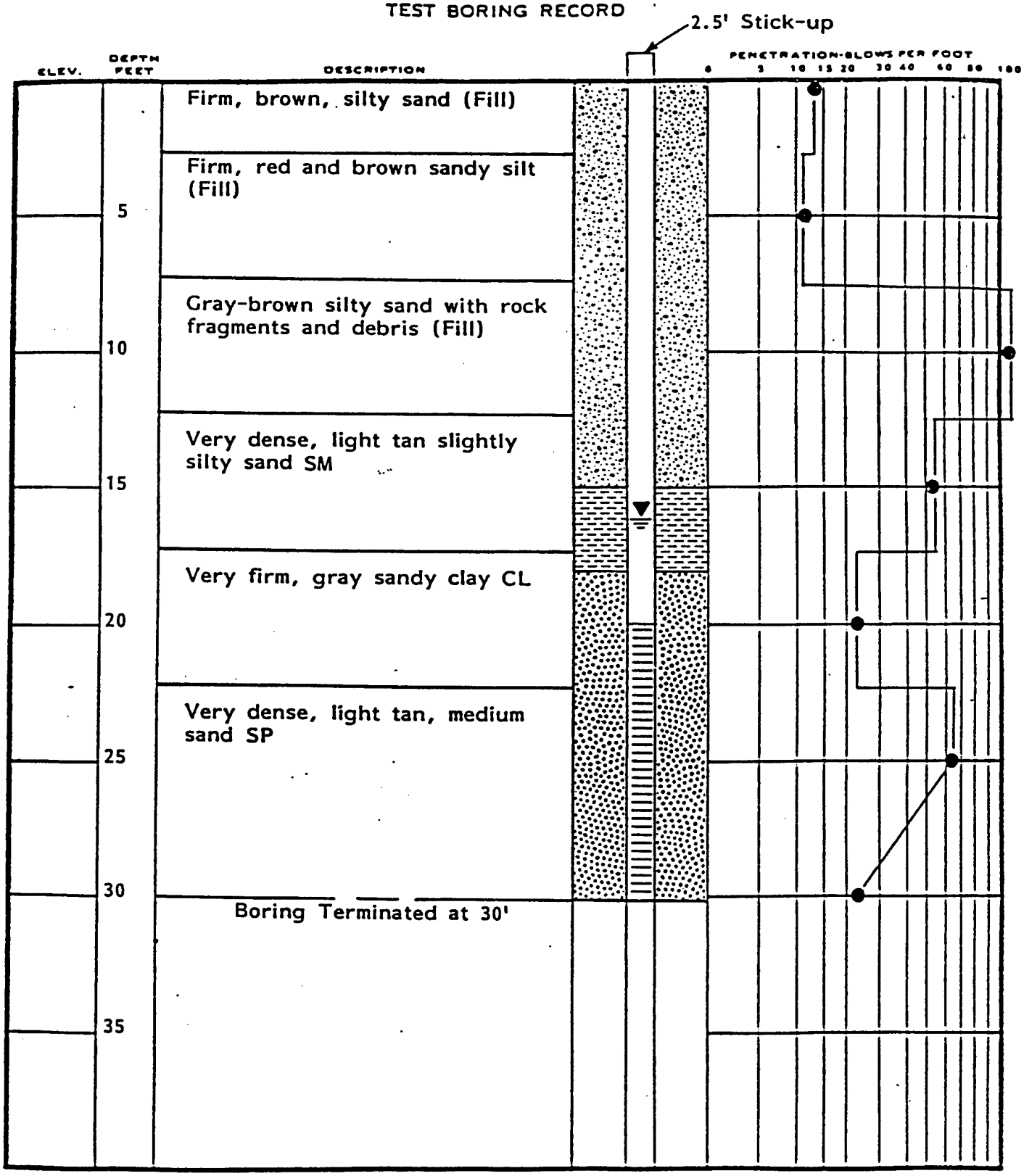
Young, L.Y., 1984, Anaerobic degradation of aromatic compounds, In: Gibson, D.R., ed.: Microbial Degradation of Aromatic Compounds. Marcel-Dekker, New York.

Zheng, C., 1990, MT3D - A Modular Three-Dimensional Transport Model for Simulation of Advection, Dispersion, and Chemical Reactions of Contaminants in Groundwater Systems; Prepared for the US Environmental Protection Agency Robert S. Kerr Environmental Research Laboratory, October 17, 1990.

APPENDIX A

BOREHOLE LOGS, CPT/LIF RESULTS, MONITORING WELL CONSTRUCTION DIAGRAMS, MONITORING WELL/POINT SAMPLING FORMS, AQUIFER TEST RESULTS, AND SURVEY DATA.

TEST BORING RECORD



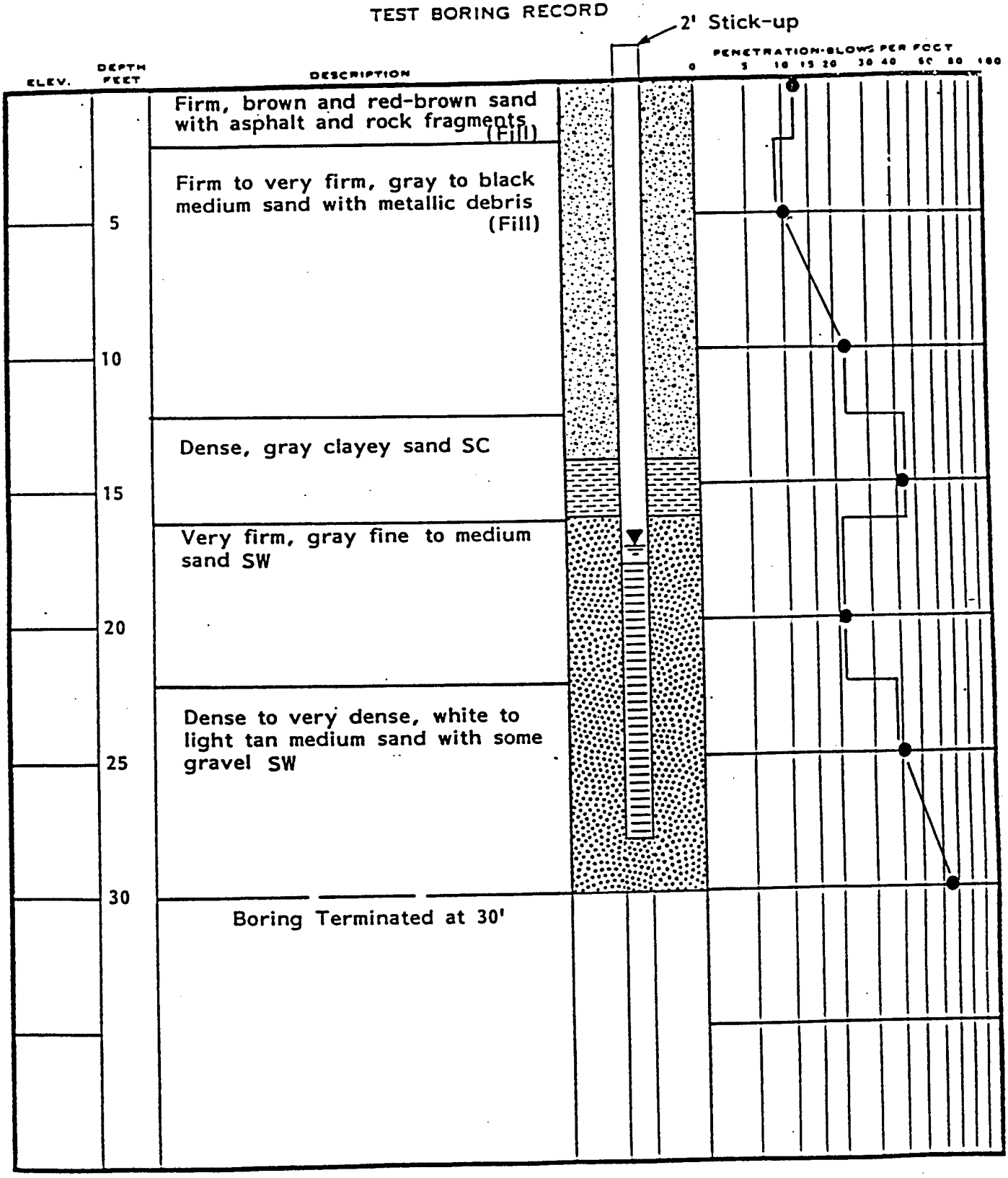
REMARKS:

2" PVC casing
Elevation not surveyed
Water level measured 11/19/86

DRILLED BY R. Banks
LOGGED BY M. Bond/Babcock
CHECKED BY J. Wilson

BORING NUMBER PZ-101
DATE STARTED 11/8/86
DATE COMPLETED 11/8/86
JOB NUMBER 602-2

TEST BORING RECORD



REMARKS:

2" PVC casing
Elevation not surveyed
Water level measured 11/19/86

DRILLED BY R.Banks
LOGGED BY M.Bond
CHECKED BY J.Wilson

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DATE STARTED 11/11/86
DATE COMPLETED 11/11/86
JOB NUMBER 602-2

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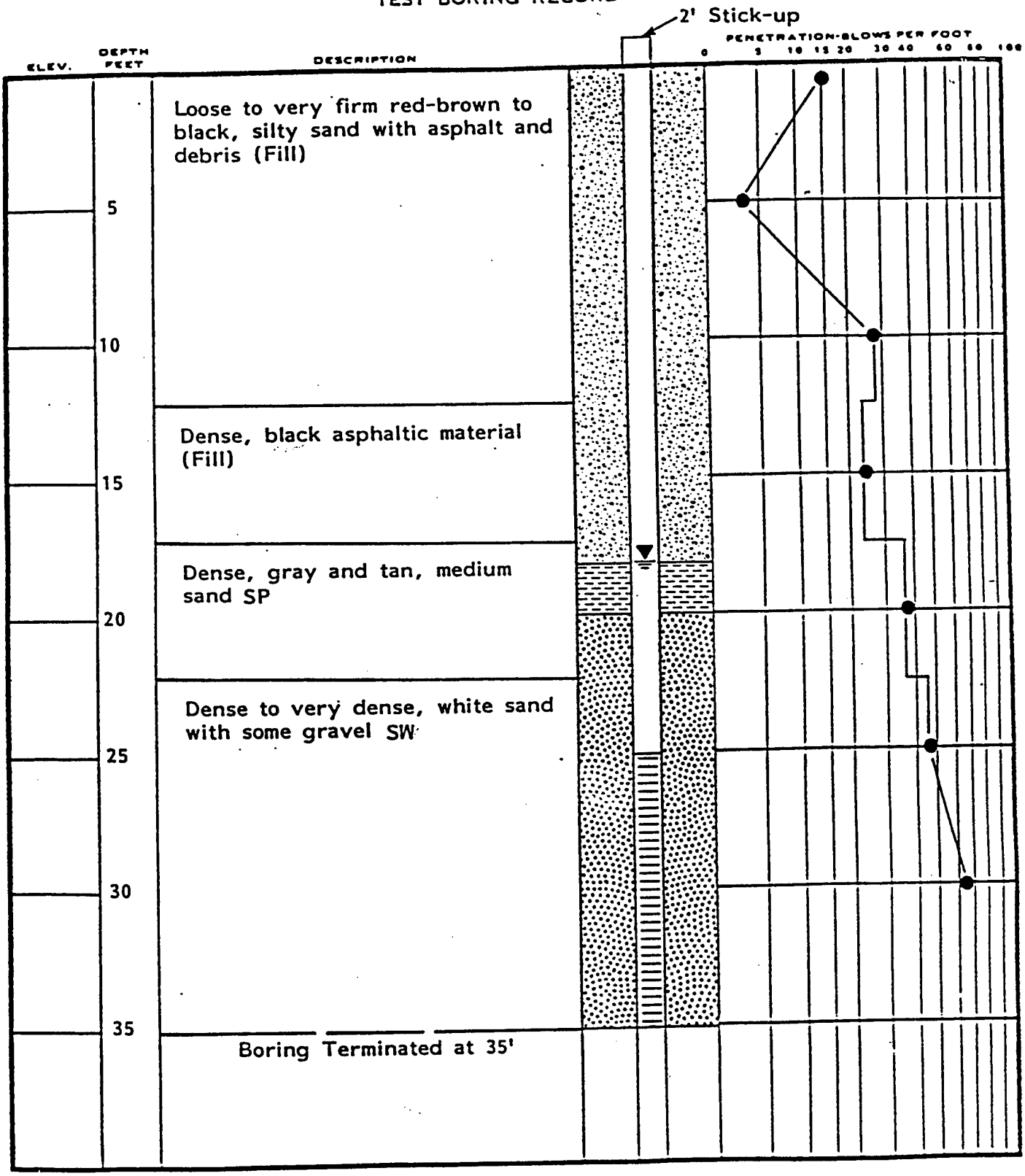

REMARKS:

2" PVC casing
Elevation not surveyed
Water level measured 11/19/86

DRILLED BY R.Banks
LOGGED BY M.Bond
CHECKED BY J.Wilson

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DATE COMPLETED 11/11/87
JOB NUMBER 602-2

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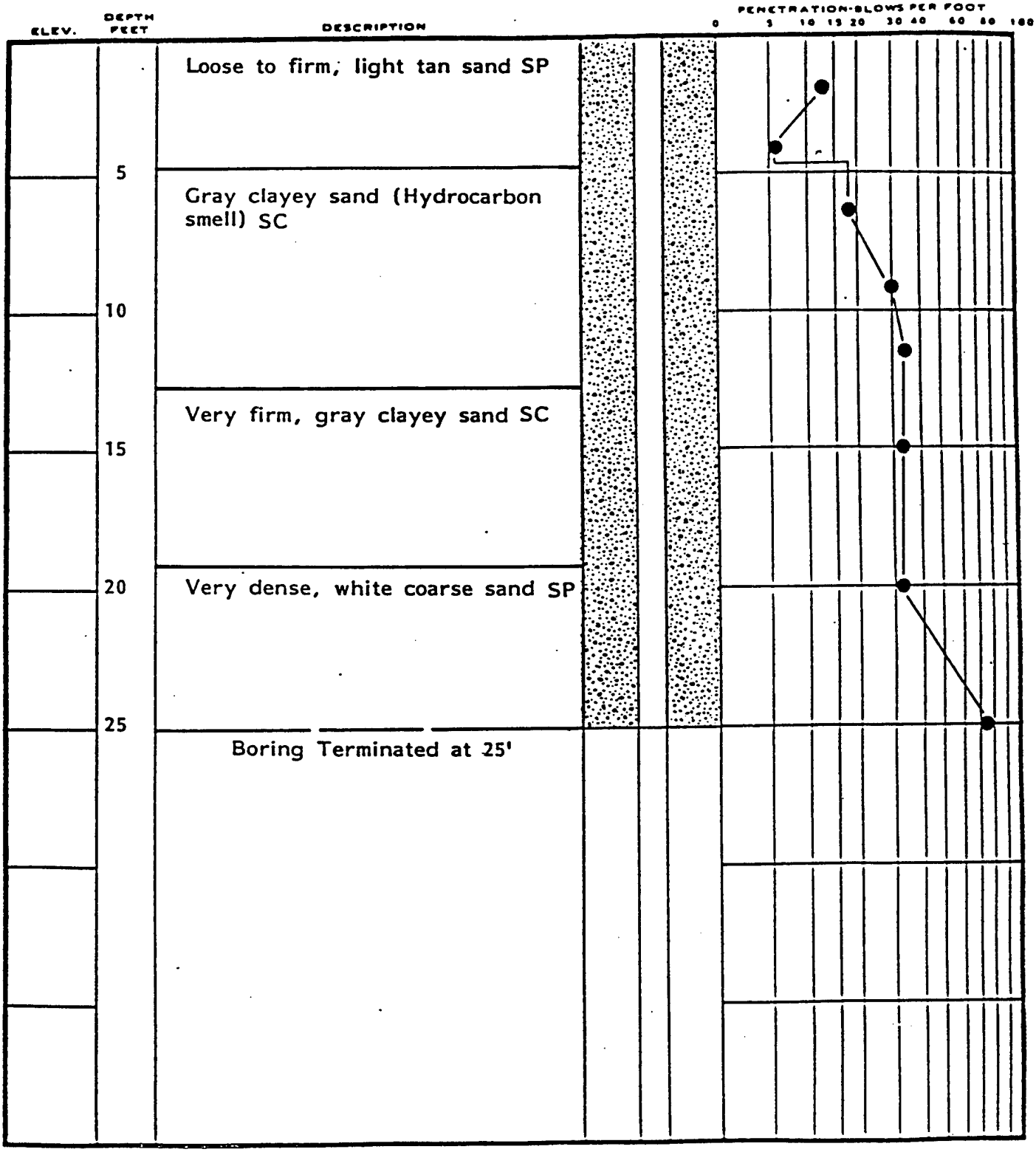

REMARKS:

DRILLED BY R. Banks
LOGGED BY M. Bond
CHECKED BY J. Wilson

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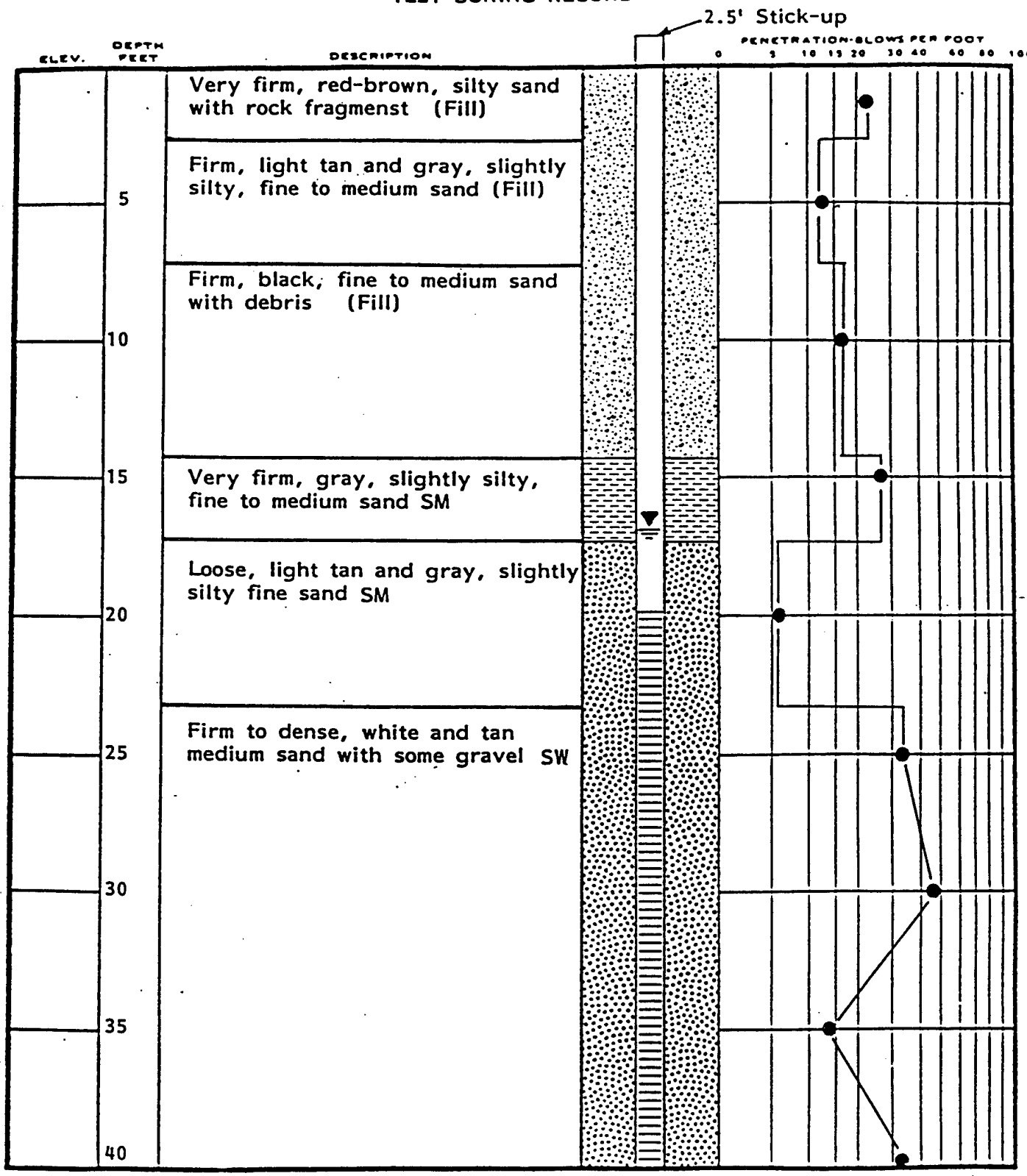
DATE COMPLETED 11/7/86
JOB NUMBER 602-2

TEST BORING RECORD



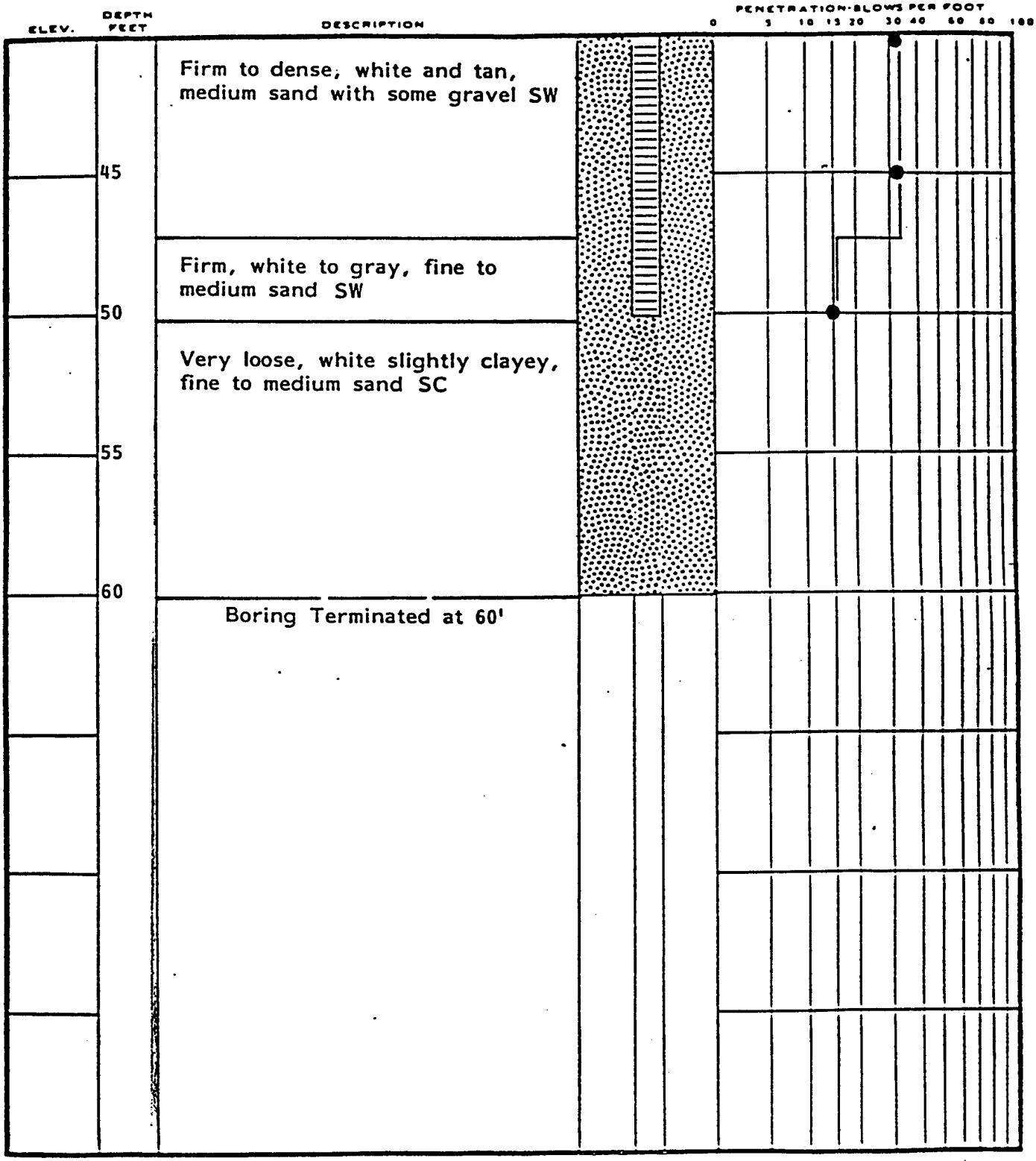
REMARKS:

Sheet 1 of 2
4" PVC casing
Elevation not surveyed
Water level measured 11/19/86

DRILLED BY R.Banks
LOGGED BY M.Bond
CHECKED BY J.Wilson

BORING NUMBER TW-101
DATE STARTED 11/9/86
DATE COMPLETED 11/9/86
JOB NUMBER 602-2

TEST BORING RECORD



REMARKS:

Sheet 2 of 2

DRILLED BY R. Banks
LOGGED BY M. Bond
CHECKED BY J. Wilson

BORING NUMBER TW-101
DATE STARTED 11/9/86
DATE COMPLETED 11/9/86
JOB NUMBER 602-2

From: Kathleen Older
To: internet.mcx:"jhansen@afceeb1.brooks.af.mil"
Date: 6/5/97 10:50am
Subject: Wells at Shaw

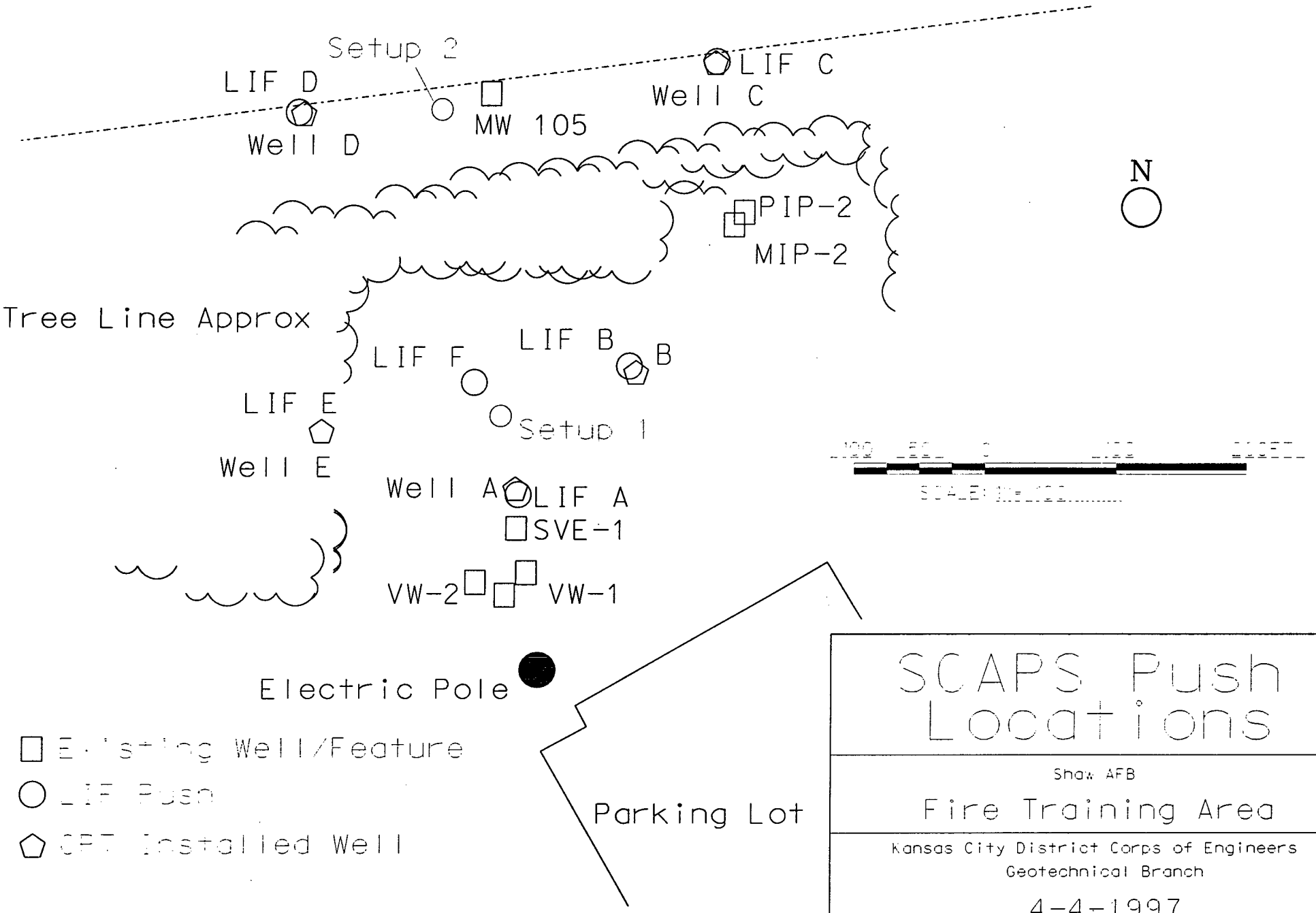
SCAPS put in 5 power punch well points at Shaw. These well points have a mechanical packer above the screen. The screen intervals are approximately 10 feet and consist of 3 one meter long flush joint sections.

Well 5EFire is opened from 13 to 23 feet. water@ 13.0 ft
Well at location B is opened 8 to 18 feet. water@ 13.5 ft
Well at location A is opened 8 to 18 feet. water@ 12.9 ft
Well at location D is opened 13 to 23 feet. water@ 15.1 ft
Well at location C is opened 4 to 14 feet. water@ 9.9 ft

All wells have well boxes which have been cemented in. No bentonite or cement was placed around the well points but the boxes should prevent surface runoff from entering well point.

CC: JDC

In addition to the above message sent to Mr. Hansen all well material was schedule 40 flush joint PVC.



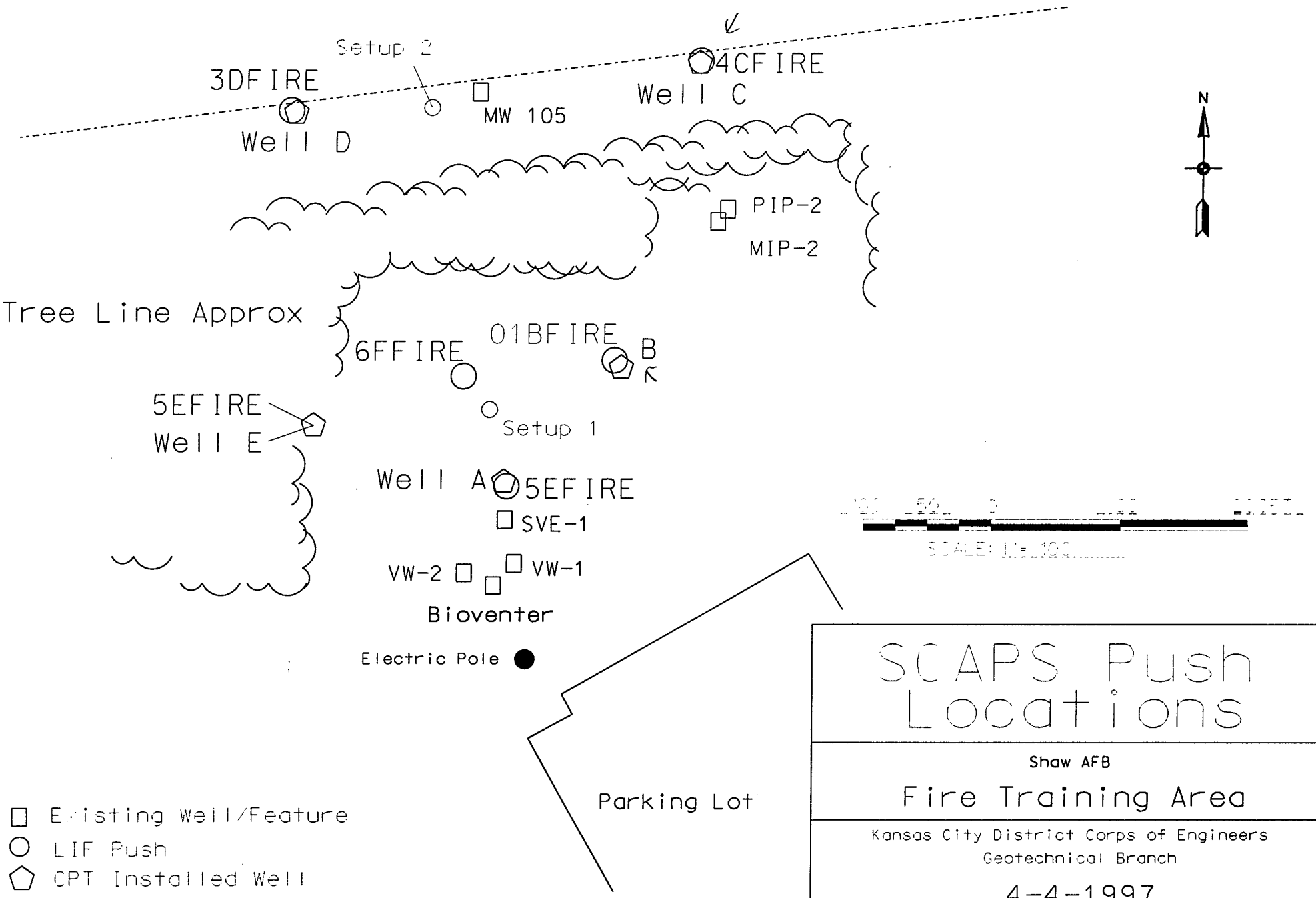
SCAPS Push Locations

Shaw AFB

Fire Training Area

Kansas City District Corps of Engineers
Geotechnical Branch

4-4-1997



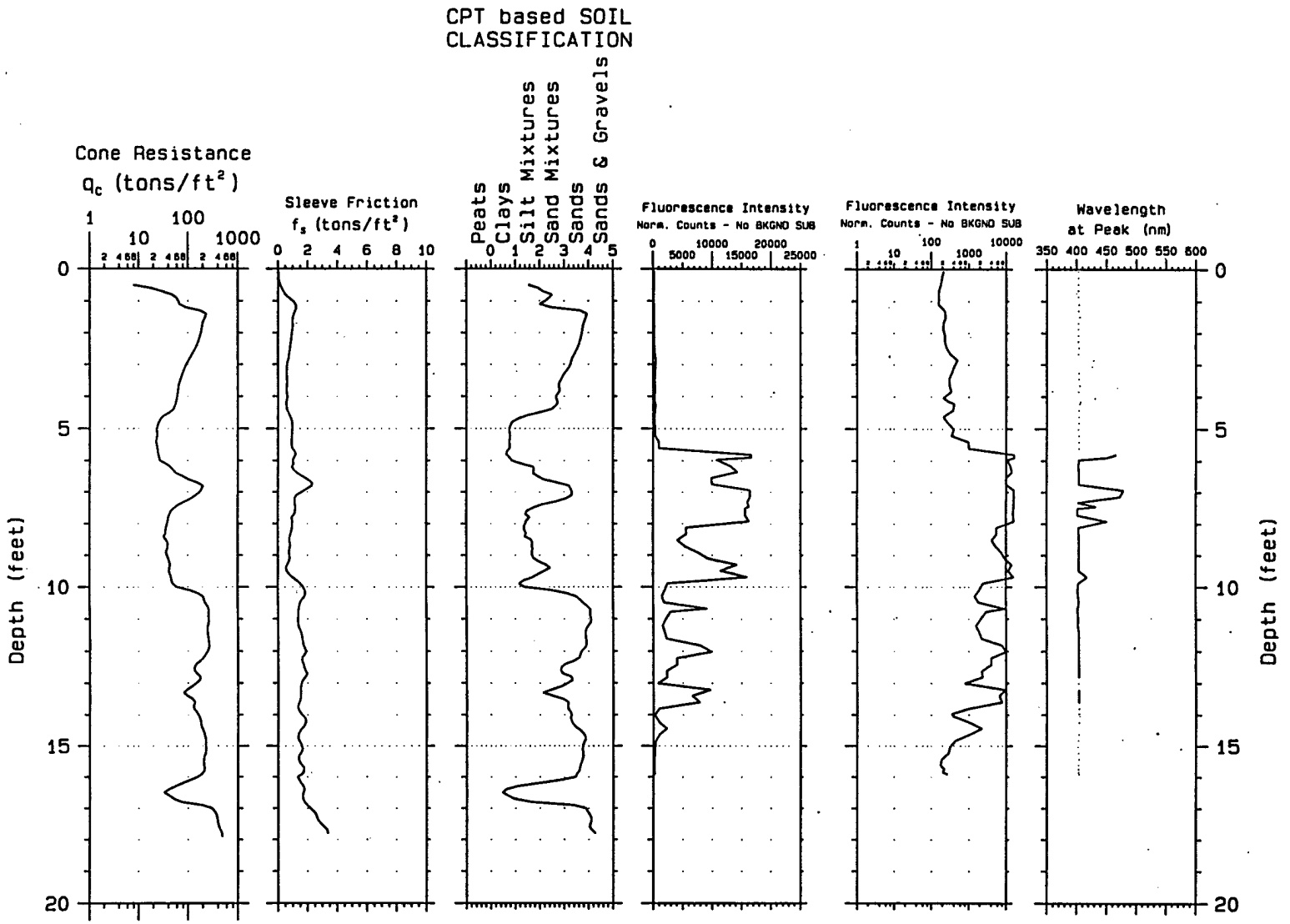
SCAPS Push Locations

Shaw AFB

Fire Training Area

Kansas City District Corps of Engineers
Geotechnical Branch

4-4-1997



Laser induced fluorescence of POL via fiber optics

U.S. Army Engineer District Kansas City Geotechnical Branch

MRK SCAPS

Site Characterization and Analysis Penetrometer System

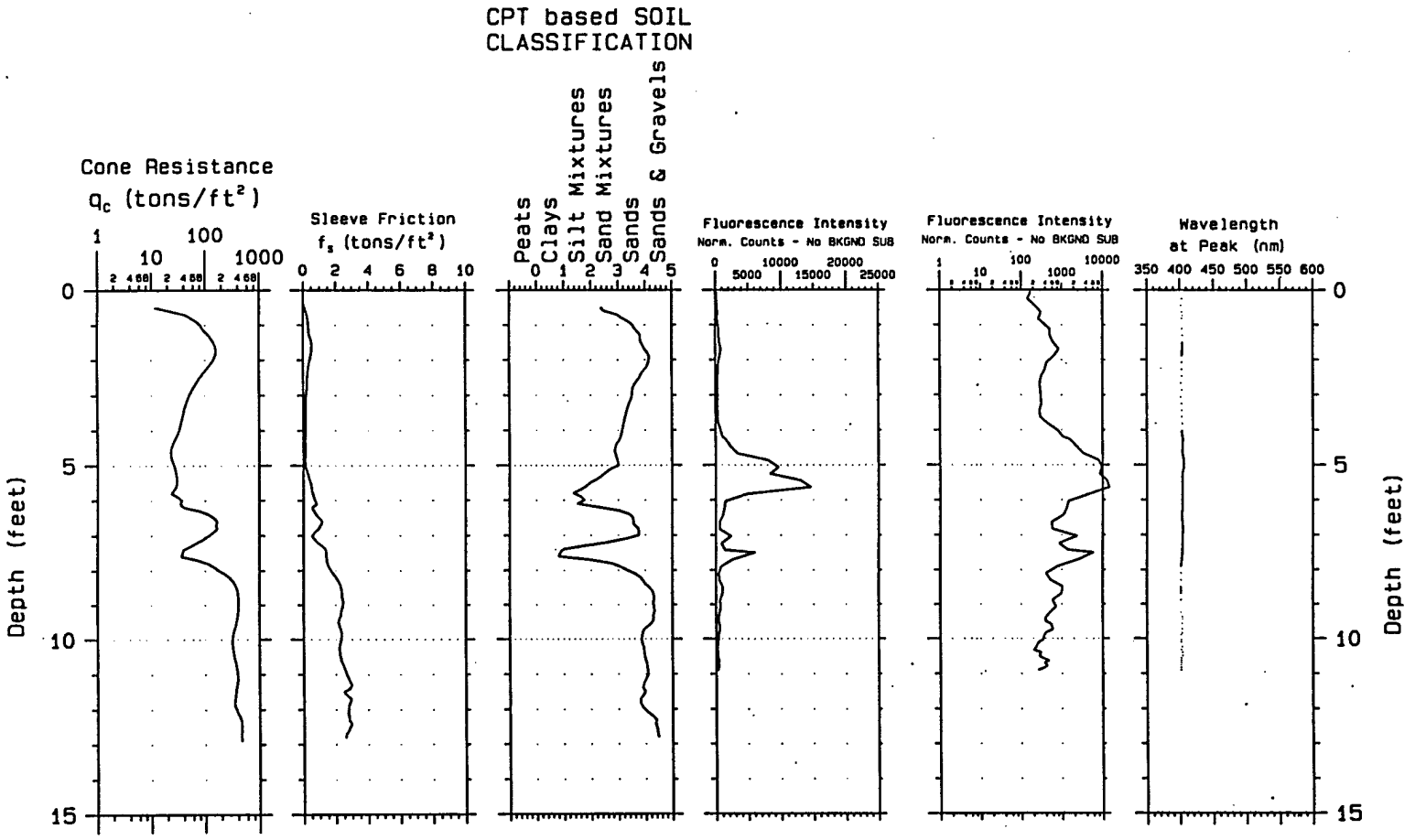
Project; Shaw AFB

Probe Depth; 18.09

Pre-Push Depth; 0

CPT; 01BFIRE

Probing date; 04-03-1997



Laser induced fluorescence of POL via fiber optics

U.S.Army Engineer District Kansas City Geotechnical Branch

MRK SCAPS

Site Characterization and Analysis Penetrometer System

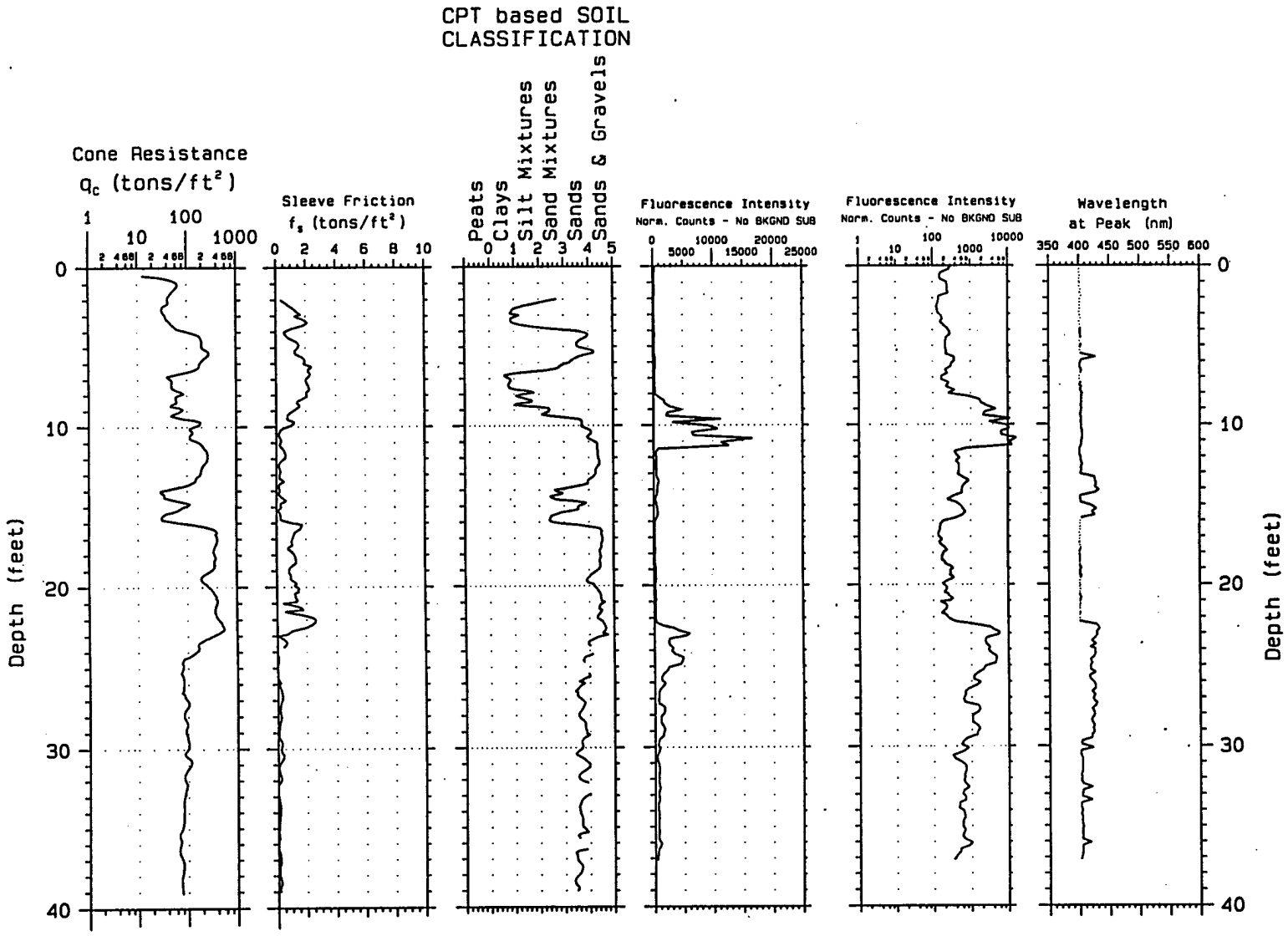
Project; Shaw AFB

Probe Depth; 13.08

Pre-Push Depth; 0

CPT; 2AFIRE

Probing date; 04-03-1997



Laser induced fluorescence of POL via fiber optics

U.S.Army Engineer District Kansas City Geotechnical Branch

MRK SCAPS

Site Characterization and Analysis Penetrometer System

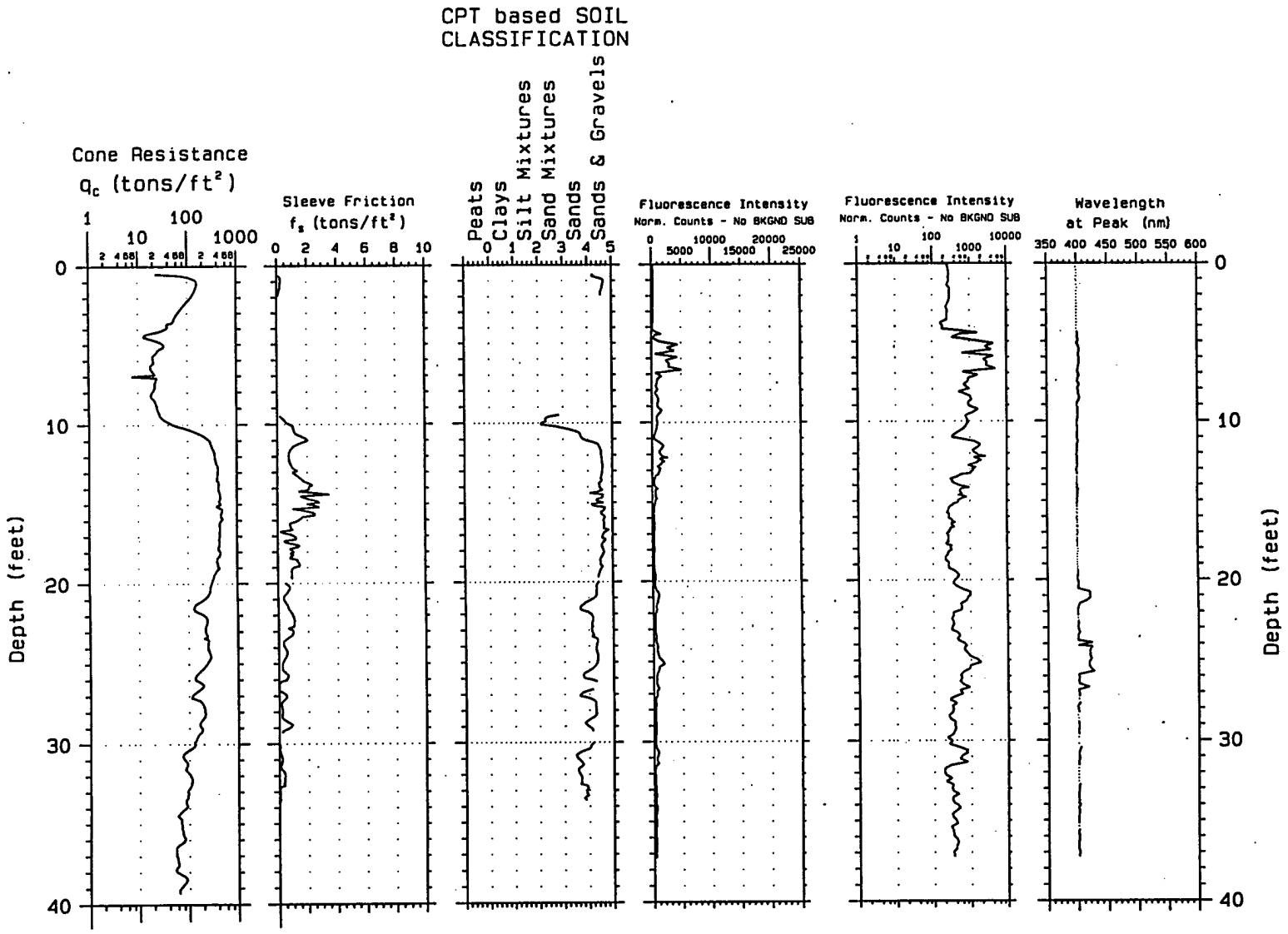
Project; Shaw AFB

Probe Depth; 39.28

Pre-Push Depth; 0

CPT; 4CFIRE

Probing date; 04-03-1997



Laser induced fluorescence of POL via fiber optics

U.S.Army Engineer District Kansas City Geotechnical Branch

MRK SCAPS

Site Characterization and Analysis Penetrometer System

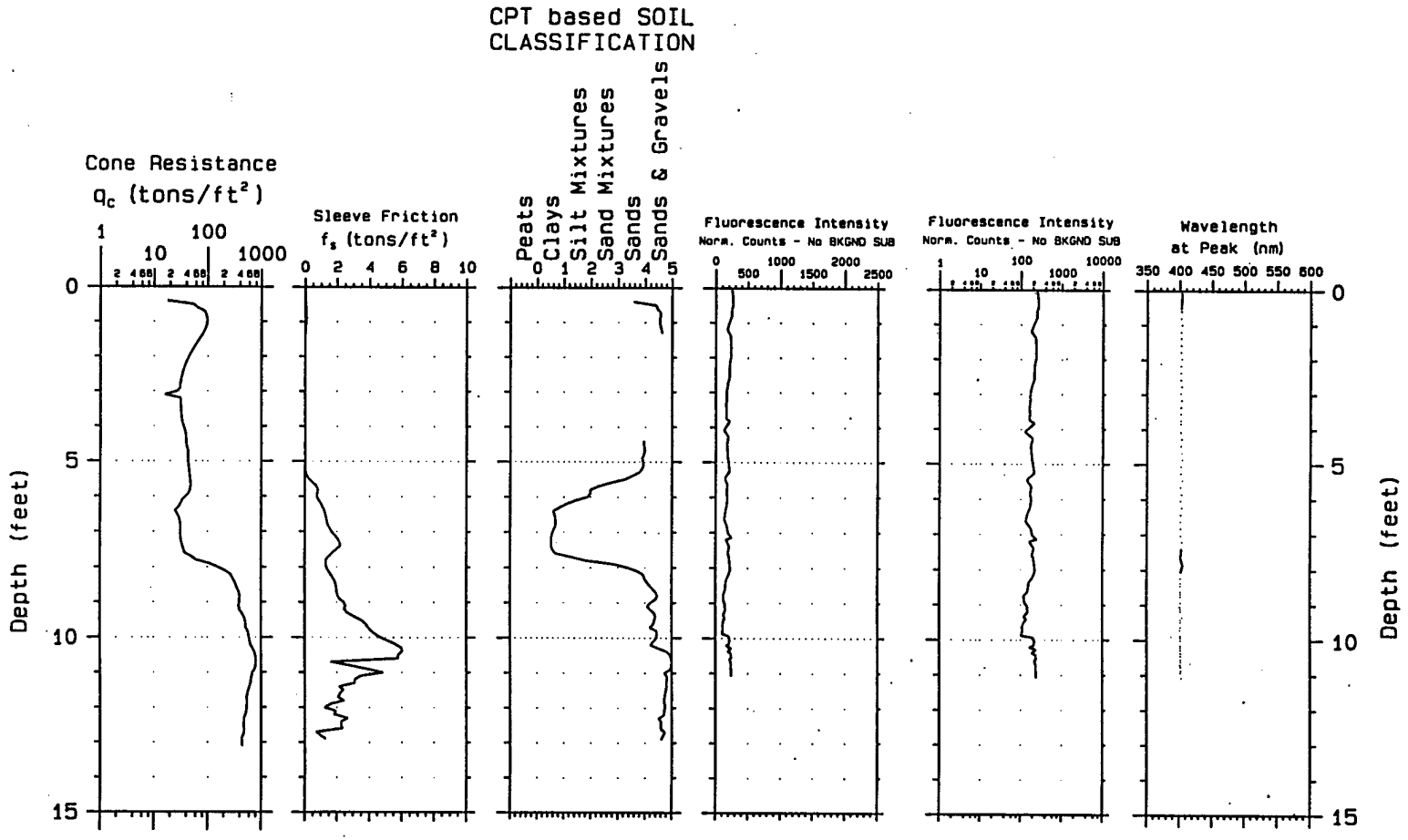
Project; Shaw AFB

Probe Depth; 39.40

Pre-Push Depth; 0

CPT; 6FFIRE

Probing date; 04-03-1997



Probing date; 04-03-1997

Laser induced fluorescence of POL via fiber optics

U.S.Army Engineer District Kansas City Geotechnical Branch

MRK SCAPS

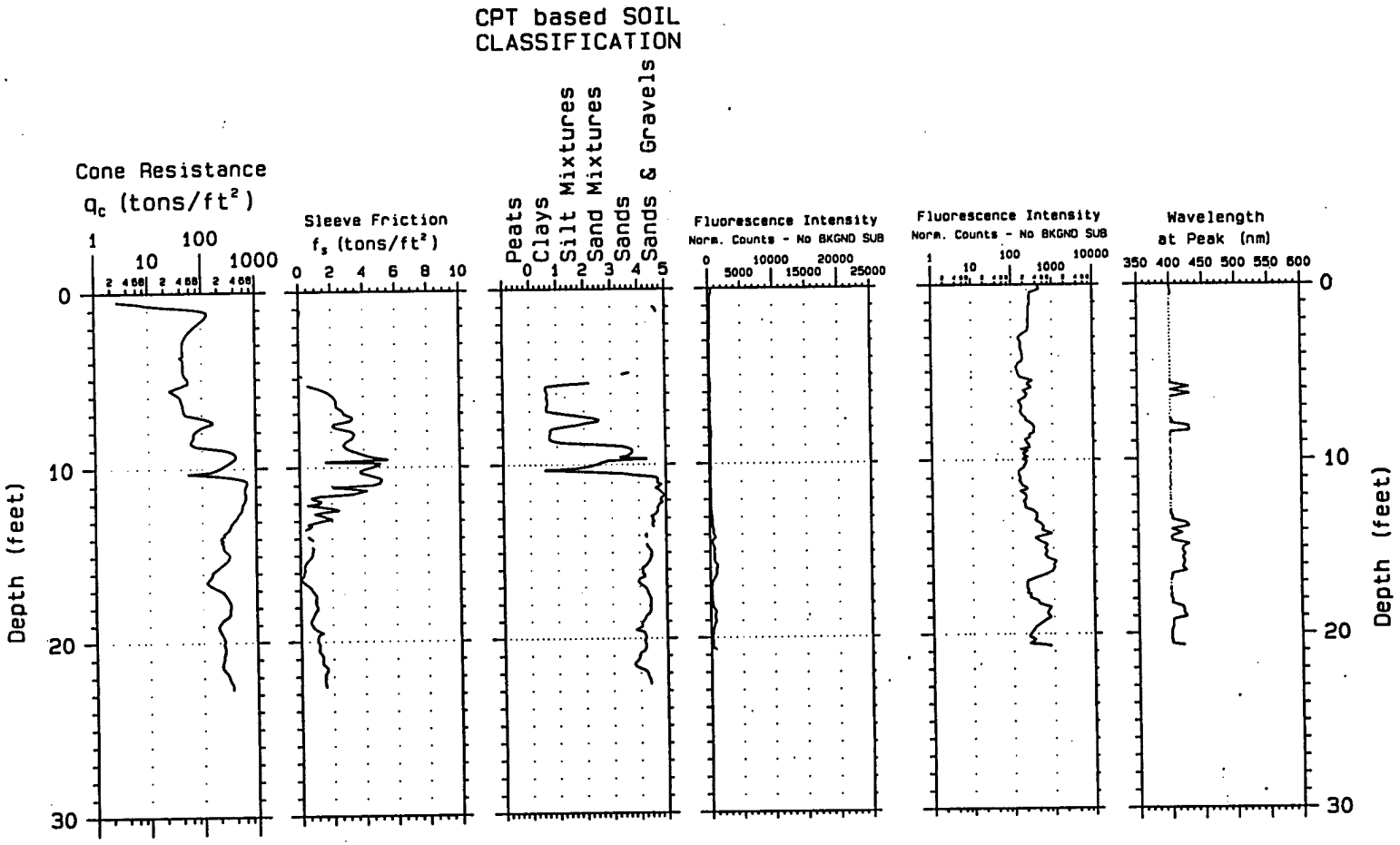
Site Characterization and Analysis Penetrometer System

Project; Shaw AFB

Probe Depth; 13.26

Pre-Push Depth; 0

CPT; 3DFIRE



Laser induced fluorescence of POL via fiber optics

U.S.Army Engineer District Kansas City Geotechnical Branch

MRK SCAPS

Site Characterization and Analysis Penetrometer System

Project; Shaw AFB

Probe Depth; 22.86

Pre-Push Depth; 0

CPT; 5EFIRE

Probing date; 04-03-1997

RUST ENVIRONMENT & INFRASTRUCTURE

GROUNDWATER MONITORING INSTALLATION DETAIL

PROJECT: OU#4/FORMER FIRE TRAINING AREA #1

LOCATION: SAFB, SUMTER, SC

CLIENT: US ARMY CORPS OF ENGINEERS

CONTRACTOR: AE DRILLING

DRILLER: B. BARNES CERTIFICATION NO: 562

RUST E&I FIELD REPRESENTATIVE: FRANK FARMER

JOB NO 81863.150

INSTALLATION NO MW-112A

TYPE OF INSTALLATION 2-IN. SCH 40 PVC MONITORING WELL

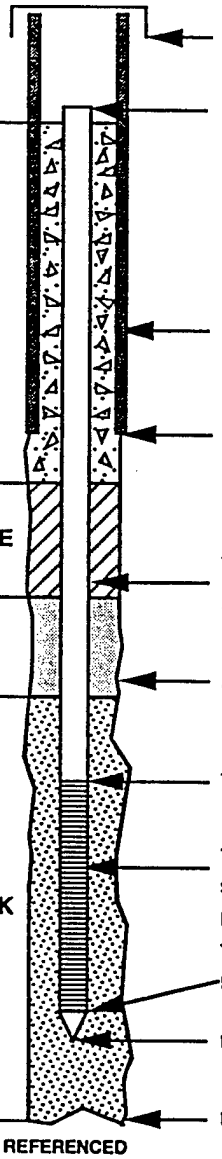
BORING NO. MW-112A

LOCATION OU #4

INSTALLATION DATE 2/4/93

SURVEY DATUM: NGVD

GROUND SURFACE ELEVATION: 215.78



SUMMARIZE SOIL CONDITIONS, BACKFILL AND SEALS (NOT TO SCALE)

Interlayered Well Graded and Poorly Graded Sand (SW/SP)

49.0 ft.

Well Graded Sand (SW)

78.0 ft.

Poorly Graded Sand (SP)

NEAT CEMENT/ BENTONITE GROUT

60.0 ft.

BENTONITE

72.05 ft.

FINE SAND

73.60 ft.

FILTERPACK SAND

TOP OF PROTECTIVE CASING (CAP OPEN)
EL. ≈218 STICKUP ≈2.0 ft.

TOP OF WELL CASING OR RISER PIPE
EL. 217.92 STICKUP 2.14 ft.

TYPE OF SURFACE SEAL: Concrete Pad

THICKNESS OF SURFACE SEAL: Approx. 6 in.

TYPE OF PROTECTIVE CASING: Anodized Aluminum

INSIDE DIAMETER: 4.0 in. Square

TOTAL LENGTH: 5.0 ft.

BOTTOM OF PROTECTIVE CASING
EL. ≈213 DEPTH ≈3.0 ft.

TYPE OF WELL CASING OR RISER PIPE: SCH 40 PVC

INSIDE DIAMETER: 2.0 in.

APPROXIMATE DIAMETER OF BOREHOLE: Approx. 6.5 in.

TOP OF SCREENED INTERVAL
EL. 136.68 DEPTH 79.64 ft.

TYPE OF SCREEN: Continuous Slot PVC

SCREEN GAUGE OR SIZE OF OPENINGS: 0.010 in.

INSIDE DIAMETER: 2.0 in.

TYPE OF BACKFILL AROUND POINT: FX-50

BOTTOM OF SCREENED INTERVAL
EL. 126.60 DEPTH 89.18 ft.

BOTTOM OF WELL
EL. 126.08 DEPTH 89.70 ft.

BOTTOM OF BOREHOLE
EL. 125.78 DEPTH 90.00 ft.

• FIGURES ABOVE REFER TO DEPTH IN FEET

• ALL DEPTHS ARE REFERENCED TO GROUND SURFACE

81.51 ft. (LENGTH OF RISER PIPE) + 10.33 ft. (LENGTH OF POINT) = 91.84 ft. (TOTAL)

BENTONITE SEALS

393020

RUST ENVIRONMENT & INFRASTRUCTURE

GROUNDWATER MONITORING INSTALLATION DETAIL

PROJECT: OU#4/FORMER FIRE TRAINING AREA #1

LOCATION: SAFB, SUMTER, SC

CLIENT: US ARMY CORPS OF ENGINEERS

CONTRACTOR: AE DRILLING

DRILLER: T. BURNETTE CERTIFICATION NO: 387

RUST E&I FIELD REPRESENTATIVE: FRANK FARMER

JOB NO 81863.150

INSTALLATION NO MW-115A

TYPE OF INSTALLATION 2-IN. SCH 40 PVC MONITORING WELL

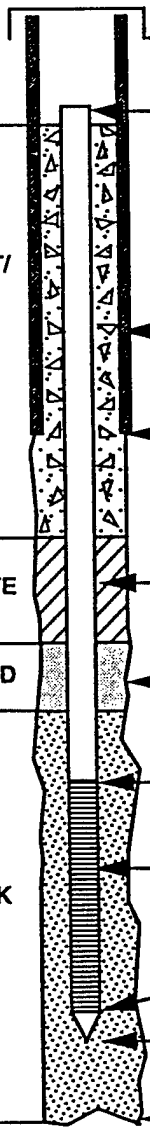
BORING NO. MW-115A

LOCATION OU #4

INSTALLATION DATE 2/18/93

SURVEY DATUM: NGVD

GROUND SURFACE ELEVATION: 202.19



SUMMARIZE SOIL CONDITIONS, BACKFILL AND SEALS (NOT TO SCALE)

Poorly Graded and Well Graded Sand (SP/SW)

16.0 ft.

Poorly Graded Sand (SP)

40.6 ft.

Well Graded Sand (SW)

56.5 ft.

Clay (CH)

63.0 ft.

Poorly Graded Sand (SP)

75.5 ft.

Sandy Clay (CL)/ Clayey Sand (SC)

NEAT CEMENT/ BENTONITE GROUT

47.49 ft.

BENTONITE

54.38 ft.

FINE SAND

56.55 ft.

FILTERPACK SAND

- FIGURES ABOVE REFER TO DEPTH IN FEET
- ALL DEPTHS ARE REFERENCED TO GROUND SURFACE

TOP OF PROTECTIVE CASING (CAP OPEN)
EL. ≈204 STICKUP ≈2.0 ft.

TOP OF WELL CASING OR RISER PIPE
EL. 204.16 STICKUP 1.97 ft.

TYPE OF SURFACE SEAL: Concrete Pad

THICKNESS OF SURFACE SEAL: Approx. 6. in.

TYPE OF PROTECTIVE CASING: Anodized Aluminum

INSIDE DIAMETER: 4.0 in. Square

TOTAL LENGTH: 5.0 ft.

BOTTOM OF PROTECTIVE CASING
EL. ≈199 DEPTH ≈3.0 ft.

TYPE OF WELL CASING OR RISER PIPE: SCH 40 PVC

INSIDE DIAMETER: 2.0 in.

APPROXIMATE DIAMETER OF BOREHOLE: Approx. 6.5 in.

TOP OF SCREENED INTERVAL
EL. 143.70 DEPTH 59.05 ft.

TYPE OF SCREEN: Continuous Slot PVC

SCREEN GAUGE OR SIZE OF OPENINGS: 0.010 in.

INSIDE DIAMETER: 2.0 in.

TYPE OF BACKFILL AROUND POINT: Morie #00N

BOTTOM OF SCREENED INTERVAL
EL. 133.30 DEPTH 68.56 ft.

BOTTOM OF WELL
EL. 133.82 DEPTH 69.08 ft.

BOTTOM OF BOREHOLE
EL. 113.19 DEPTH 89.0 ft.

60.74 ft. LENGTH OF RISER PIPE + 10.31 ft. LENGTH OF POINT = 71.05 ft. TOTAL

BENTONITE SEALS

RUST ENVIRONMENT & INFRASTRUCTURE

GROUNDWATER MONITORING INSTALLATION DETAIL

PROJECT: OU#4/FORMER FIRE TRAINING AREA #1
LOCATION: SAFB, SUMTER, SC
CLIENT: US ARMY CORPS OF ENGINEERS
CONTRACTOR: AE DRILLING
DRILLER: LEE REEVES/ BILL BARNES CERTIFICATION NO: 562
RUST E&I FIELD REPRESENTATIVE: FRANK FARMER

JOB NO 81863.150
INSTALLATION NO MW-116
TYPE OF INSTALLATION 2-IN. SCH 40 PVC MONITORING WELL
BORING NO. MW-116
LOCATION OU #4
INSTALLATION DATE 2/1/93

SURVEY DATUM: NGVD
GROUND SURFACE ELEVATION: 217.20

SUMMARIZE SOIL CONDITIONS, BACKFILL AND SEALS (NOT TO SCALE)

Poorly Graded Sand (SP)

NEAT CEMENT/ BENTONITE GROUT

3.89 ft.

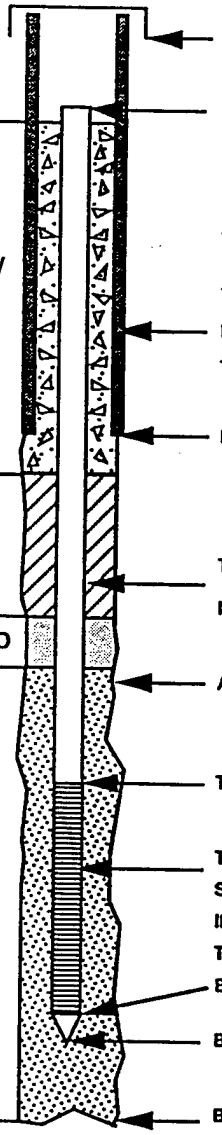
BENTONITE

5.53 ft.

FINE SAND

6.48 ft.

FILTERPACK SAND



TOP OF PROTECTIVE CASING (CAP OPEN)
EL. ≈219 STICKUP ≈2.0 ft.

TOP OF WELL CASING OR RISER PIPE
EL. 219.46 STICKUP 2.26 ft.

TYPE OF SURFACE SEAL: Concrete Pad
THICKNESS OF SURFACE SEAL: Approx. 6 in.

TYPE OF PROTECTIVE CASING: Anodized Aluminum
INSIDE DIAMETER: 4.0 in. Square
TOTAL LENGTH: 5.0 ft.

BOTTOM OF PROTECTIVE CASING
EL. ≈214 DEPTH ≈3.0 ft.

TYPE OF WELL CASING OR RISER PIPE: SCH 40 PVC
INSIDE DIAMETER: 2.0 in.

APPROXIMATE DIAMETER OF BOREHOLE: Approx. 10 in.

TOP OF SCREENED INTERVAL
EL. 208.87 DEPTH 8.33 ft.

TYPE OF SCREEN: Continuous Wrap PVC
SCREEN GAUGE OR SIZE OF OPENINGS: 0.010 in.
INSIDE DIAMETER: 2.0 in.
TYPE OF BACKFILL AROUND POINT: FX-50

BOTTOM OF SCREENED INTERVAL
EL. 194.36 DEPTH 22.84 ft.

BOTTOM OF WELL
EL. 193.85 DEPTH 23.35 ft.

BOTTOM OF BOREHOLE
EL. 190.20 DEPTH 27.0 ft.

• FIGURES ABOVE REFER TO DEPTH IN FEET
• ALL DEPTHS ARE REFERENCED TO GROUND SURFACE

10.31 ft. LENGTH OF RISER PIPE + 15.30 ft. LENGTH OF POINT = 25.61 ft. TOTAL

BENTONITE SEALS

393020

RUST ENVIRONMENT & INFRASTRUCTURE

GROUNDWATER MONITORING INSTALLATION DETAIL

PROJECT: OU#4/FORMER FIRE TRAINING AREA #1

LOCATION: SAFB, SUMTER, SC

CLIENT: US ARMY CORPS OF ENGINEERS

CONTRACTOR: AE DRILLING

DRILLER: LEE REEVES/ BILL BARNES CERTIFICATION NO: 562

RUST E&I FIELD REPRESENTATIVE: FRANK FARMER

JOB NO 81863.150

INSTALLATION NO MW-116A

TYPE OF INSTALLATION 2-IN. SCH 40 PVC MONITORING WELL

BORING NO. MW-116A

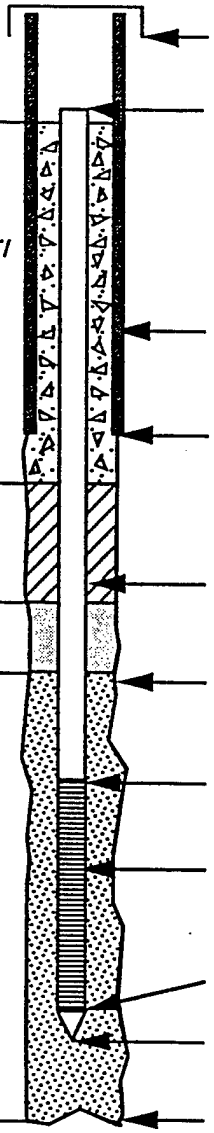
LOCATION OU #4

INSTALLATION DATE 1/29/93

SURVEY DATUM: NGVD

GROUND SURFACE ELEVATION: 217.14

SUMMARIZE SOIL CONDITIONS, BACKFILL AND SEALS (NOT TO SCALE)



TOP OF PROTECTIVE CASING (CAP OPEN)
EL. ≈219 STICKUP ≈2.0 ft.

TOP OF WELL CASING OR RISER PIPE
EL. 219.48 STICKUP 2.34 ft.

TYPE OF SURFACE SEAL: Concrete Pad
THICKNESS OF SURFACE SEAL: 6.23 ft.

TYPE OF PROTECTIVE CASING: Anodized Aluminium
INSIDE DIAMETER: 4.0 in. Square
TOTAL LENGTH: 5.0 ft.

BOTTOM OF PROTECTIVE CASING
EL. ≈214 DEPTH ≈3.0 ft.

TYPE OF WELL CASING OR RISER PIPE: SCH 40 PVC
INSIDE DIAMETER: 2.0 in.

APPROXIMATE DIAMETER OF BOREHOLE: Approx. 6.5 in.

TOP OF SCREENED INTERVAL
EL. 131.94 DEPTH 85.20 ft.

TYPE OF SCREEN: Continuous Wrap PVC
SCREEN GAUGE OR SIZE OF OPENINGS: 0.010 in.
INSIDE DIAMETER: 2.0 in.
TYPE OF BACKFILL AROUND POINT: FX-50

BOTTOM OF SCREENED INTERVAL
EL. 122.40 DEPTH 94.74 ft.

BOTTOM OF WELL
EL. 121.89 DEPTH 95.25 ft.

BOTTOM OF BOREHOLE
EL. 120.14 DEPTH 97.00 ft.

• FIGURES ABOVE REFER TO DEPTH IN FEET

• ALL DEPTHS ARE REFERENCED TO GROUND SURFACE

87.26 ft. (LENGTH OF RISER PIPE) + 10.33 ft. (LENGTH OF POINT) = 97.59 ft. (TOTAL)

BENTONITE SEALS

RUST ENVIRONMENT & INFRASTRUCTURE

GROUNDWATER MONITORING INSTALLATION DETAIL

PROJECT: OU#4/FORMER FIRE TRAINING AREA #1

LOCATION: SAFB, SUMTER, SC

CLIENT: US ARMY CORPS OF ENGINEERS

CONTRACTOR: AE DRILLING

DRILLER: LEE REEVES/ BILL BARNES CERTIFICATION NO: 562

RUST E&I FIELD REPRESENTATIVE: FRANK FARMER

JOB NO 81863.150

INSTALLATION NO MW-117

TYPE OF INSTALLATION 2-IN. SCH 40 PVC MONITORING WELL

BORING NO. MW-117

LOCATION OU #4

INSTALLATION DATE 2/5/93

SURVEY DATUM: NGVD

GROUND SURFACE ELEVATION: 213.89

SUMMARIZE SOIL CONDITIONS, BACKFILL AND SEALS (NOT TO SCALE)

Poorly Graded Sand (SP)

PROTECTIVE CONCRETE PAD

0.72 ft.

BENTONITE

2.56 ft.

FINE SAND

3.0 ft.

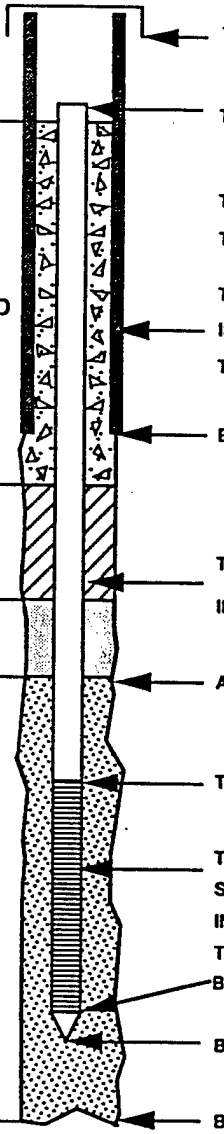
3.53 ft.

Clayey Sand (SC)

12.5 ft.

FILTERPACK SAND

Well Graded Sand (SW)



TOP OF PROTECTIVE CASING (CAP OPEN)
EL. ≈216 STICKUP ≈2.5 ft.

TOP OF WELL CASING OR RISER PIPE
EL. 216.42 STICKUP 2.53 ft.

TYPE OF SURFACE SEAL: Concrete Pad

THICKNESS OF SURFACE SEAL: Approx. 1.5 ft.

TYPE OF PROTECTIVE CASING: Anodized Aluminum

INSIDE DIAMETER: 4.0 in. Square

TOTAL LENGTH: ≈3.0 ft.

BOTTOM OF PROTECTIVE CASING
EL. ≈211 DEPTH ≈2.5 ft.

TYPE OF WELL CASING OR RISER PIPE: SCH 40 PVC

INSIDE DIAMETER: 2.0 in.

APPROXIMATE DIAMETER OF BOREHOLE: Approx. 10 in.

TOP OF SCREENED INTERVAL
EL. 207.44 DEPTH 6.45 ft.

TYPE OF SCREEN: Continuous Slot PVC

SCREEN GAUGE OR SIZE OF OPENINGS: 0.010 in.

INSIDE DIAMETER: 2.0 in.

TYPE OF BACKFILL AROUND POINT: FX-50

BOTTOM OF SCREENED INTERVAL
EL. 192.99 DEPTH 20.90 ft.

BOTTOM OF WELL
EL. 192.48 DEPTH 21.41 ft.

BOTTOM OF BOREHOLE
EL. 188.39 DEPTH 25.50 ft.

• FIGURES ABOVE REFER TO DEPTH IN FEET

• ALL DEPTHS ARE REFERENCED TO GROUND SURFACE

8.70 ft. LENGTH OF RISER PIPE + 15.24 ft. LENGTH OF POINT = 23.94 ft. TOTAL

BENTONITE SEALS

393020

RUST ENVIRONMENT & INFRASTRUCTURE

GROUNDWATER MONITORING INSTALLATION DETAIL

PROJECT: OU#4/FORMER FIRE TRAINING AREA #1

LOCATION: SAFB, SUMTER, SC

CLIENT: US ARMY CORPS OF ENGINEERS

CONTRACTOR: AE DRILLING

DRILLER: T. BURNETTE CERTIFICATION NO: 387

RUST E&I FIELD REPRESENTATIVE: FRANK FARMER

JOB NO 81863.150

INSTALLATION NO MW-118

TYPE OF INSTALLATION 2-IN. SCH 40 PVC MONITORING WELL

BORING NO. MW-118

LOCATION OU #4

INSTALLATION DATE 2/15/93

SURVEY DATUM: NGVD

GROUND SURFACE ELEVATION: 201.12

SUMMARIZE SOIL CONDITIONS, BACKFILL AND SEALS (NOT TO SCALE)

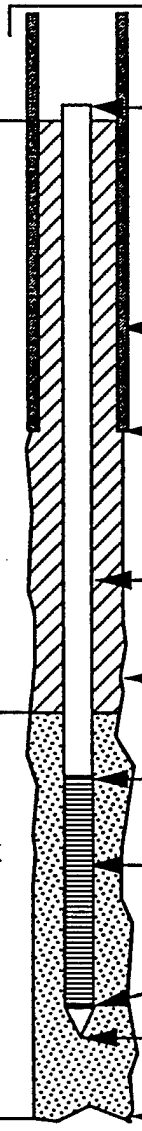
Poorly Graded Sand (SP)

8.5 ft.

Clayey Sand (SC)

9.0 ft.

Poorly Graded Sand (SP)



TOP OF PROTECTIVE CASING (CAP OPEN)
EL. ≈203 STICKUP ≈2.0 ft.

TOP OF WELL CASING OR RISER PIPE
EL. 203.51 STICKUP 2.39 ft.

TYPE OF SURFACE SEAL: Concrete Pad

THICKNESS OF SURFACE SEAL: Approx. 6 in.

TYPE OF PROTECTIVE CASING: Anodized Aluminum

INSIDE DIAMETER: 4.0 in square

TOTAL LENGTH: Approx. 2.25 ft.

BOTTOM OF PROTECTIVE CASING
EL. ≈200.87 DEPTH ≈0.25 ft.

TYPE OF WELL CASING OR RISER PIPE: SCH 40 PVC

INSIDE DIAMETER: 2.0 in.

APPROXIMATE DIAMETER OF BOREHOLE: Approx. 10 in.

TOP OF SCREENED INTERVAL
EL. 200.27 DEPTH 0.85 ft.

TYPE OF SCREEN: Continuous Wrap PVC

SCREEN GAUGE OR SIZE OF OPENINGS: 0.010 in.

INSIDE DIAMETER: 2.0 in.

TYPE OF BACKFILL AROUND POINT: Morie #00N

BOTTOM OF SCREENED INTERVAL
EL. 190.76 DEPTH 10.36 ft.

BOTTOM OF WELL
EL. 190.24 DEPTH 10.88 ft.

BOTTOM OF BOREHOLE
EL. 189.12 DEPTH 12.00 ft.

• FIGURES ABOVE REFER TO DEPTH IN FEET

• ALL DEPTHS ARE REFERENCED TO GROUND SURFACE

2.96 ft.	+	10.31 ft.	=	13.27 ft.
LENGTH OF RISER PIPE		LENGTH OF POINT		TOTAL

BENTONITE SEALS

RUST ENVIRONMENT & INFRASTRUCTURE

GROUNDWATER MONITORING INSTALLATION DETAIL

PROJECT: OU#4

LOCATION: SAFB, SOUTH CAROLINA

CLIENT: US ARMY CORPS OF ENGINEERS

CONTRACTOR: AE DRILLING

DRILLER: P. O'DONNELL CERTIFICATION NO: 519

RUST E&I FIELD REPRESENTATIVE: B. E. CULP

JOB NO 81961.230

INSTALLATION NO MW-119A

TYPE OF INSTALLATION 2-IN. SCH 40 PVC MONITORING WELL

BORING NO. MW-119A

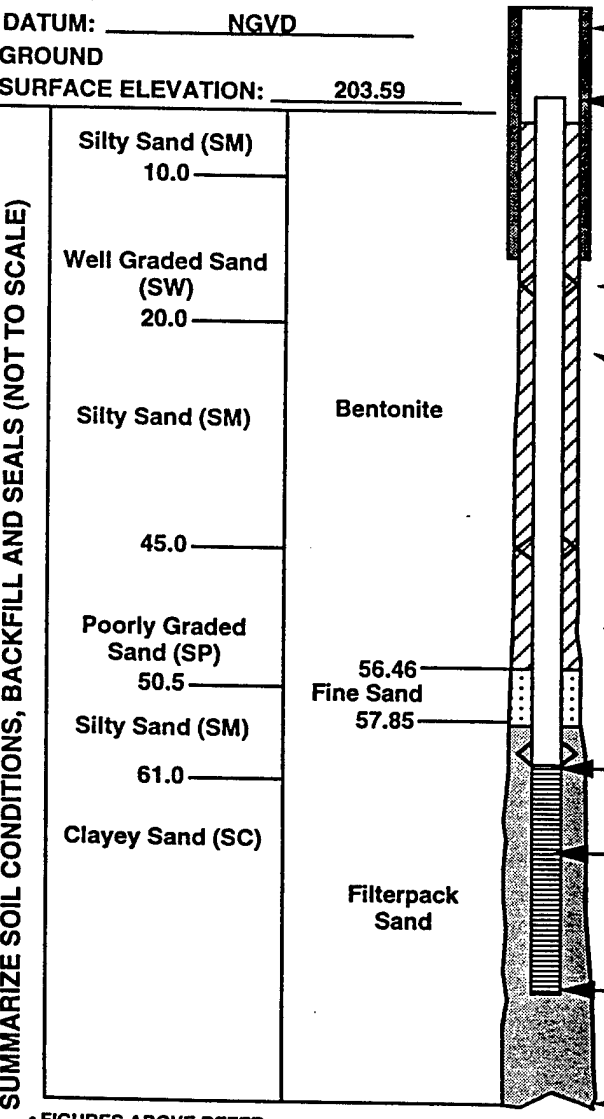
LOCATION SEE SITE PLAN

INSTALLATION DATE 5/17/94

SURVEY DATUM: NGVD

GROUND SURFACE ELEVATION: 203.59

SUMMARIZE SOIL CONDITIONS, BACKFILL AND SEALS (NOT TO SCALE)



TOP OF PROTECTIVE CASING (CAP OPEN)
EL. 205.84 ft. STICKUP 2.25 ft.

TOP OF WELL CASING OR RISER PIPE
EL. 205.89 ft. STICKUP 2.30 ft.

THICKNESS OF SURFACE SEAL 56.46 ft.

TYPE OF PROTECTIVE CASING Annodized Aluminum
INSIDE DIAMETER 4.0 inch
TOTAL LENGTH 5.0 feet

BOTTOM OF PROTECTIVE CASING
EL. 200.89 ft. DEPTH 2.70 ft.

APPROXIMATE DIAMETER OF BOREHOLE 7 3/4 inch

TYPE OF WELL CASING OR RISER PIPE Schedule 40 PVC
INSIDE DIAMETER 2.0 inch

TOP OF WELL POINT
EL. 122.91 ft. DEPTH 59.92

TYPE OF WELL POINT Schedule 40 PVC
SCREEN GAUGE OR SIZE OF OPENINGS .010 inch
INSIDE DIAMETER 2.0 inch
TYPE OF BACKFILL AROUND POINT FX 50

BOTTOM OF WELL POINT
EL. 133.29 ft. DEPTH 70.30 ft.

BOTTOM OF BOREHOLE
EL. 126.59 ft. DEPTH 77.00 ft.

• FIGURES ABOVE REFER TO DEPTH IN FEET

• ALL DEPTHS ARE REFERENCED TO GROUND SURFACE

62.27 ft. LENGTH OF RISER PIPE + 10.33 ft. LENGTH OF POINT = 72.60 ft. TOTAL

BENTONITE SEALS

RUST ENVIRONMENT & INFRASTRUCTURE

SOIL VAPOR EXTRACTION WELL INSTALLATION DETAIL

PROJECT: OU#4/FORMER FIRE TRAINING AREA #1
LOCATION: SAFB, SUMTER, SC
CLIENT: US ARMY CORPS OF ENGINEERS
CONTRACTOR: AE DRILLING
DRILLER: LEE REEVES/ BILL BARNES CERTIFICATION NO: 562
RUST E&I FIELD REPRESENTATIVE: FRANK FARMER

JOB NO G-3169.15
INSTALLATION NO SVE-1
TYPE OF INSTALLATION 4-IN. SCH 40 PVC VAPOR EXTRACTION WELL
BORING NO. SVE-1
LOCATION OU #4
INSTALLATION DATE 2/9/93

SURVEY DATUM: NGVD
GROUND SURFACE ELEVATION: ≈216.00

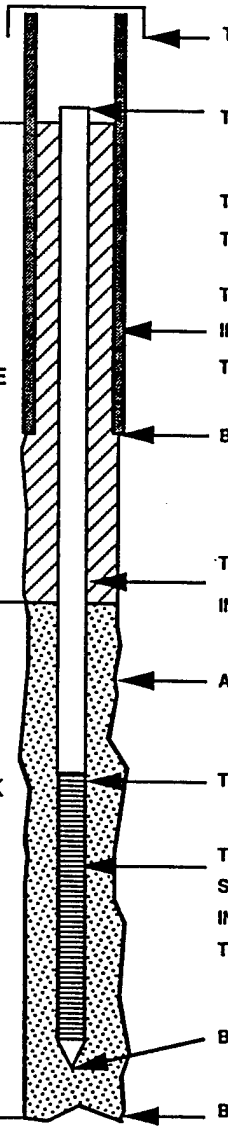
SUMMARIZE SOIL CONDITIONS, BACKFILL AND SEALS (NOT TO SCALE)

Poorly Graded Sand (SP)

BENTONITE

2.57 ft.

FILTERPACK SAND



TOP OF PROTECTIVE CASING (CAP OPEN)
EL. ≈219 STICKUP ≈3 ft.

TOP OF WELL CASING OR RISER PIPE
EL. ≈219 STICKUP ≈3 ft.

TYPE OF SURFACE SEAL: Concrete Pad
THICKNESS OF SURFACE SEAL: 6.0 in.

TYPE OF PROTECTIVE CASING: Anodized Aluminum
INSIDE DIAMETER: 6.0 in. square
TOTAL LENGTH: ≈4 ft.

BOTTOM OF PROTECTIVE CASING
EL. ≈214 DEPTH ≈2 ft.

TYPE OF WELL CASING OR RISER PIPE: SCH 40 PVC
INSIDE DIAMETER: 4.0 in.

APPROXIMATE DIAMETER OF BOREHOLE: Approx. 10 in.

TOP OF WELL POINT
EL. ≈213 DEPTH 2.87 ft.

TYPE OF SCREEN: Continuous Wrap PVC
SCREEN GAUGE OR SIZE OF OPENINGS: 0.010 in.
INSIDE DIAMETER: 4.0 in.
TYPE OF BACKFILL AROUND POINT: FX-50

BOTTOM OF WELL POINT
EL. ≈207 DEPTH 8.17 ft.

BOTTOM OF BOREHOLE
EL. ≈207 DEPTH 9.0 ft.

• FIGURES ABOVE REFER TO DEPTH IN FEET
• ALL DEPTHS ARE REFERENCED TO GROUND SURFACE

5.87 ft. (LENGTH OF RISER PIPE) + 5.30 ft. (LENGTH OF POINT) = 11.17 ft. (TOTAL)

BENTONITE SEALS

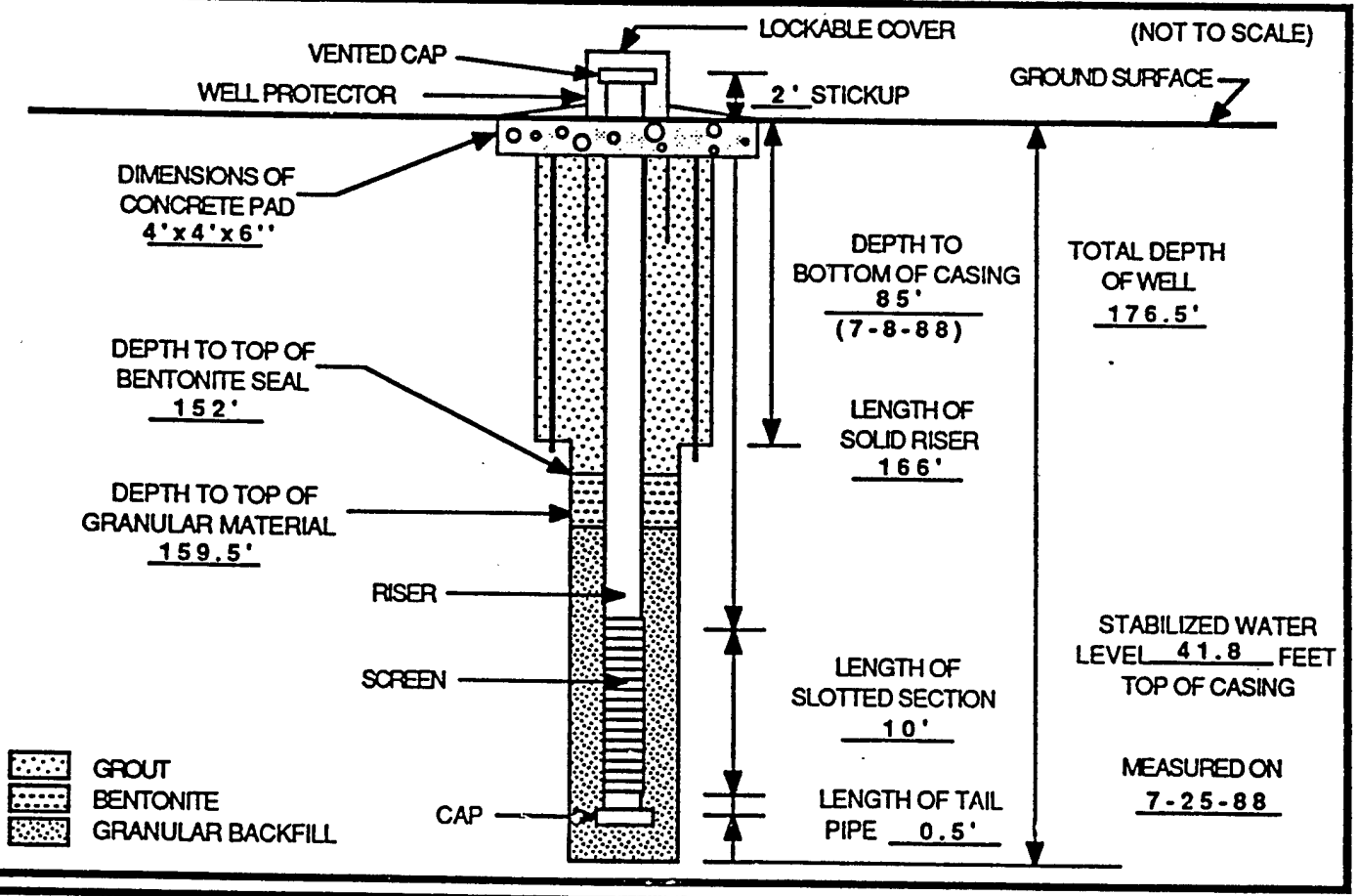
TYPE III MONITORING WELL INSTALLATION DIAGRAM

LAW ENVIRONMENTAL, INC.
GOVERNMENT SERVICES DIVISION
KENNESAW, GEORGIA

WELL NO. MW-105D
JOB NO. 11-8509-01
DATE 7-13-88 TIME 1900
WELL LOCATION SHAW AFB SITE 1, ADJACENT MW-105

GROUND SURFACE ELEVATION ~ 213.16'
TOP OF SCREEN ELEVATION 49.16'
REFERENCE POINT ELEVATION 215.16'
TYPE SAND PACK SC#89-M GRADATION GP
SAND PACK MANUFACTURER BECKER SAND & GRAVEL
SCREEN MATERIAL PVC-CONTINUOUS WRAP
MANUFACTURER JOHNSON
RISER MATERIAL PVC
MANUFACTURER BRAINARD KILMAN
RISER DIAMETER 2" ID
DRILLING TECHNIQUE (above casing) MUD ROTARY
BIT SIZE AND TYPE 9 7/8" TRICONE
DRILLING TECHNIQUE (below casing) MUD ROTARY
BIT SIZE AND TYPE 5 7/8" TRICONE

BENTONITE TYPE QUIK GEL
MANUFACTURER NL BAROID DIV.
CEMENT TYPE PORTLAND TYPE I
MANUFACTURER GIANT CEMENT CO.
BOREHOLE DIAMETER 10" OUTER, 6" INNER
SCREEN DIAMETER 2" ID SLOT SIZE 0.010
LAW ENVIRONMENTAL, INC.
FIELD REPRESENTATIVE MUNGIN-DAVIS
DRILLING CONTRACTOR LAW ENGINEERING, INC.
AMOUNT BENTONITE USED 6 BAGS
AMOUNT CEMENT USED 29 BAGS
AMOUNT SAND USED 10 GALLONS
STATIC WATER DEPTH (after dev.) 42.20' (TOC)
TYPE OF CASING PVC - 6"



QA / QC

INSTALLED BY: R. BANKS INSTALLATION OBSERVED BY: QM-D
DISCREPANCIES: STICK UP 2' BEFORE INSTALLATION OF BLADDER PUMP

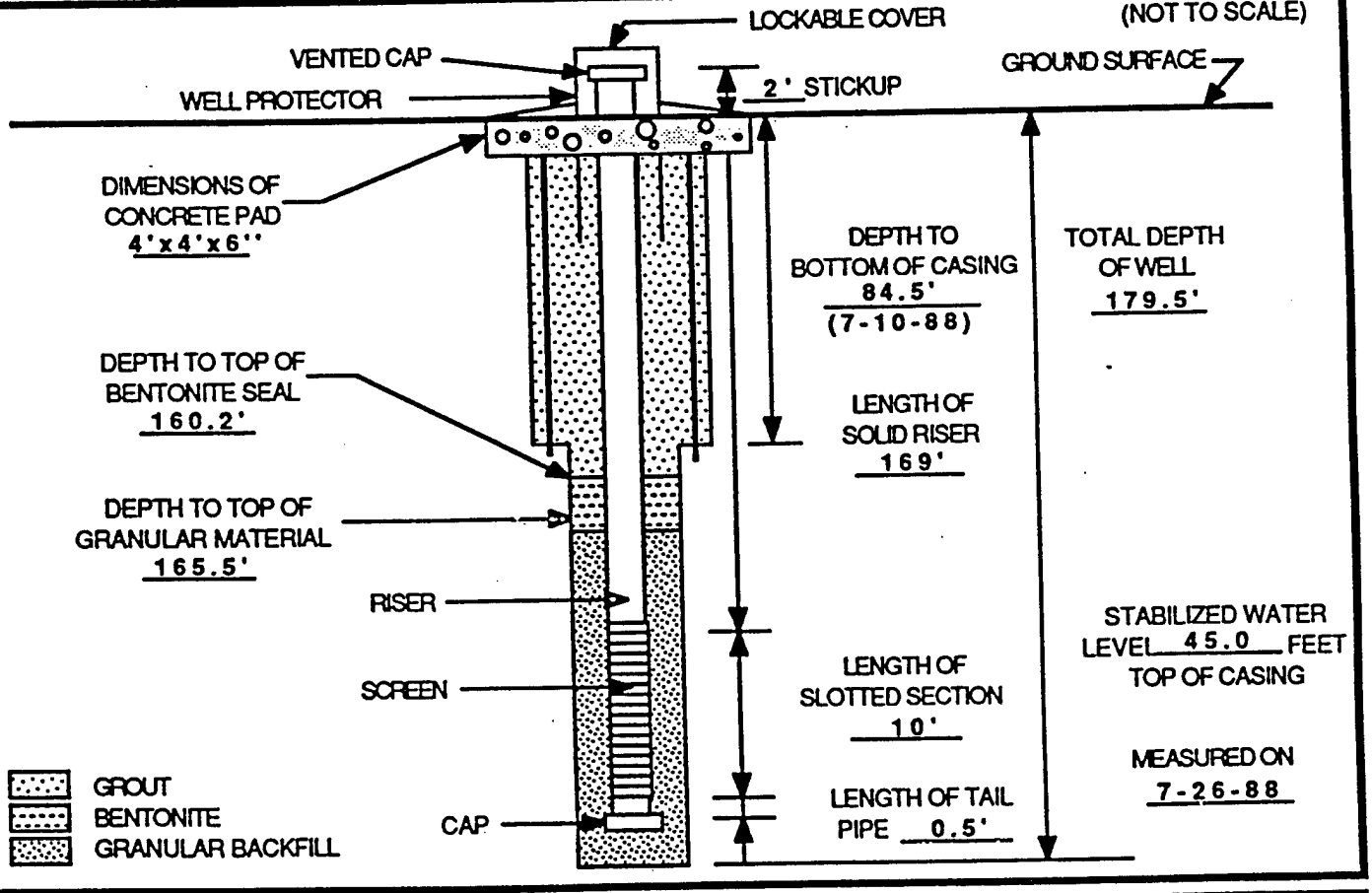
TYPE III MONITORING WELL INSTALLATION DIAGRAM

LAW ENVIRONMENTAL, INC.
GOVERNMENT SERVICES DIVISION
KENNESAW, GEORGIA

WELL NO. MW-106D
JOB NO. 11-8509-01
DATE 7-21-88 TIME 1600
WELL LOCATION SHAW AFB SITE 1, ADJACENT MW-106

GROUND SURFACE ELEVATION ~ 217.02'
TOP OF SCREEN ELEVATION 50.02'
REFERENCE POINT ELEVATION 219.02'
TYPE SAND PACK SC#89-M GRADATION GP
SAND PACK MANUFACTURER BECKER SAND & GRAVEL
SCREEN MATERIAL PVC-CONTINUOUS WRAP
MANUFACTURER JOHNSON
RISER MATERIAL PVC
MANUFACTURER BRAINARD KILMAN
RISER DIAMETER 2" ID
DRILLING TECHNIQUE (above casing) MUD ROTARY
BIT SIZE AND TYPE 9 7/8" TRICONE
DRILLING TECHNIQUE (below casing) MUD ROTARY
BIT SIZE AND TYPE 5 7/8" TRICONE

BENTONITE TYPE QUIK GEL
MANUFACTURER NL BAROID DIV.
CEMENT TYPE PORTLAND TYPE I
MANUFACTURER GIANT CEMENT CO.
BOREHOLE DIAMETER 10" OUTER, 6" INNER
SCREEN DIAMETER 2" ID SLOT SIZE 0.010
LAW ENVIRONMENTAL, INC FIELD REPRESENTATIVE MUNGIN-DAVIS, ZAUNER
DRILLING CONTRACTOR LAW ENGINEERING, INC.
AMOUNT BENTONITE USED 8 BAGS
AMOUNT CEMENT USED 26 BAGS
AMOUNT SAND USED 20 GALLONS
STATIC WATER DEPTH (after dev.) 46.14' (TOC)
TYPE OF CASING PVC - 6"



QA / QC

INSTALLED BY: C. IVEY INSTALLATION OBSERVED BY: QM-D
DISCREPANCIES: STICK UP 2' BEFORE INSTALLATION OF BLADDER PUMP

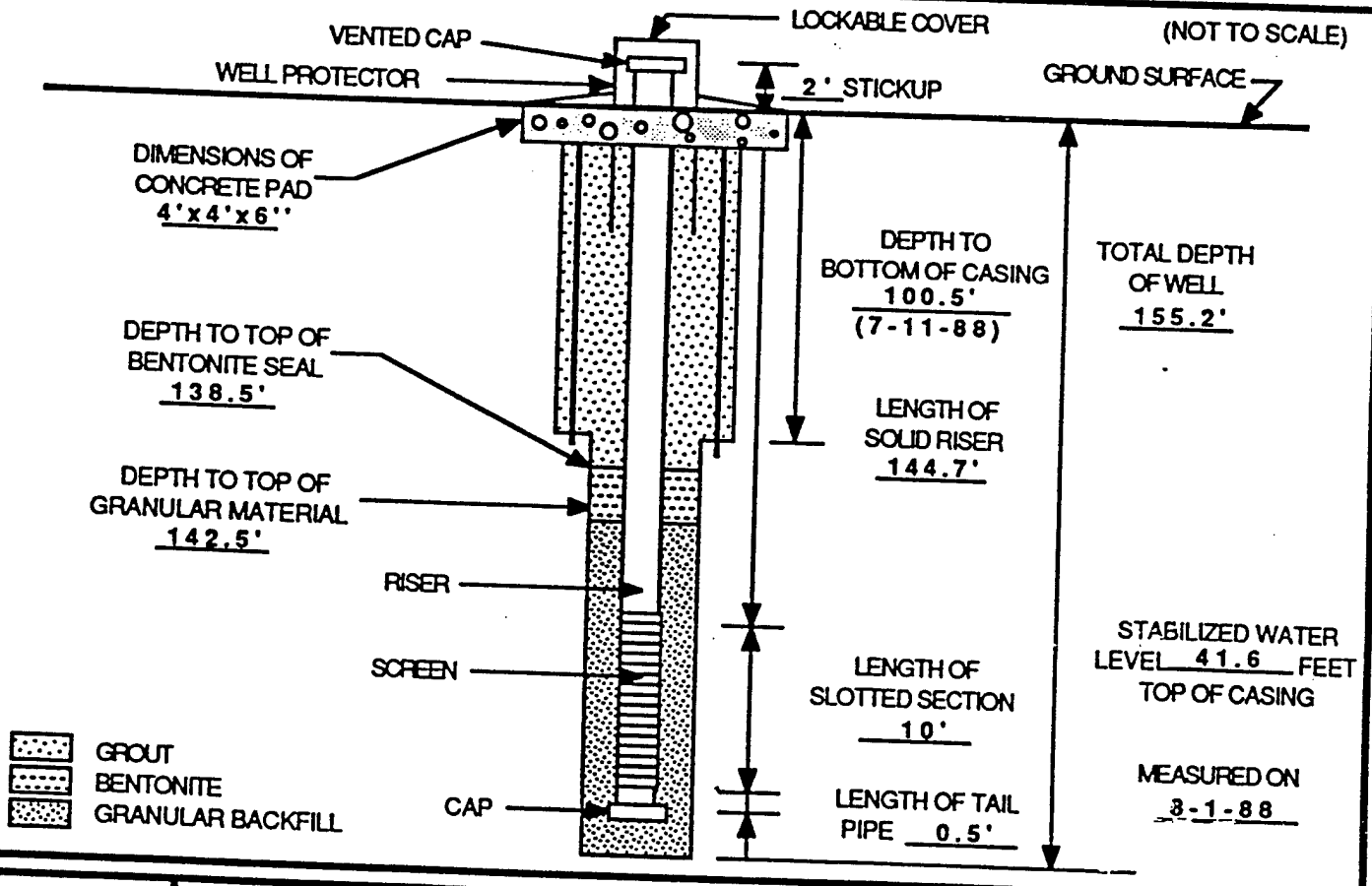
TYPE III MONITORING WELL INSTALLATION DIAGRAM

LAW ENVIRONMENTAL, INC.
GOVERNMENT SERVICES DIVISION
KENNESAW, GEORGIA

WELL NO. MW-112D
JOB NO. 11-8509-01
DATE 7-24-88 TIME 1145
WELL LOCATION SHAW AFB SITE 1, ADJACENT MW-112

GROUND SURFACE ELEVATION ~ 215.72'
TOP OF SCREEN ELEVATION 73.02'
REFERENCE POINT ELEVATION 217.72'
TYPE SAND PACK SC#89-M GRADATION GP
SAND PACK MANUFACTURER BECKER SAND & GRAVEL
SCREEN MATERIAL PVC-CONTINUOUS WRAP
MANUFACTURER JOHNSON
RISER MATERIAL PVC
MANUFACTURER BRAINARD KILMAN
RISER DIAMETER 2" ID
DRILLING TECHNIQUE (above casing) MUD ROTARY
BIT SIZE AND TYPE 9 7/8" TRICONE
DRILLING TECHNIQUE (below casing) MUD ROTARY
BIT SIZE AND TYPE 5 7/8" TRICONE

BENTONITE TYPE QUIK GEL
MANUFACTURER NL BAROID DIV.
CEMENT TYPE PORTLAND TYPE I
MANUFACTURER GIANT CEMENT CO.
BOREHOLE DIAMETER 10" OUTER, 6" INNER
SCREEN DIAMETER 2" ID SLOT SIZE 0.010
LAW ENVIRONMENTAL, INC
FIELD REPRESENTATIVE MUNGIN-DAVIS, ZAUNER
DRILLING CONTRACTOR LAW ENGINEERING, INC.
AMOUNT BENTONITE USED 7 BAGS
AMOUNT CEMENT USED 29 BAGS
AMOUNT SAND USED 15 GALLONS
STATIC WATER DEPTH (after dev.) 44.09' (TOC)
TYPE OF CASING PVC - 6" & 10"



QA / QC

INSTALLED BY: C. IVEY INSTALLATION OBSERVED BY: QM-D
DISCREPANCIES: STICK UP 2' BEFORE INSTALLATION OF BLADDER PUMP

Shaw AFB OU4 | Water Levels | 5/17/97

Well	DTW (feet)
MW-105	13.54
MW-105D	Couldn't measure
MW-106	17.79
MW-106D	Couldn't measure due to dedicated pump tubing
MW-107	11.43
MW-111	21.05
MW-112	15.06
MW-112A	19.71
MW-112D	NM (dedicated pump tubing in well - could not get probe past)
MW-113	7.19
MW-113A	7.46
MW-114	7.28
MW-115	4.52
MW-115A	7.18
MW-116	15.28
MW-116A	21.06
MW-117	14.73
MW-118	4.06
TW-101	18.73
MPA	12.92
MP B	14.78
MP C	10.25
MP D	15.18

13-782 500 SHEETS, FILLER 5 SQUARE
42-381 50 SHEETS EYE-EASE® 5 SQUARE
42-382 100 SHEETS EYE-EASE® 5 SQUARE
42-390 200 SHEETS EYE-EASE® 5 SQUARE
42-392 100 RECYCLED WHITE 5 SQUARE
42-399 200 RECYCLED WHITE 5 SQUARE
Made in U.S.A.
National® Brand

MONITORING WELL DEVELOPMENT RECORD

Job Number: 722450.37020
Location Shaw AFB
Well Identification MP A

Job Name: AFCEE-RNA
by Cindy Merrill Date: 5/15/97
Measurement Datum TOC 1/2" PVC

Pre-Development Information

Time (Start): 12:30p

Water Level: 13.54

Total Depth of Well: 17.5

Water Characteristics
Color milky grey Clear (Cloudy)
Odor: None Weak (Moderate) Strong
Any Films or Immiscible Material slight sheen
pH 6.26 Temperature (°C) 22.
Specific Conductance ~~(µS/cm)~~ 0.307 mS/cm
Dissolved Oxygen (mg/L) 1.2
Redox (mV) -58

Well Volume = 0.04 gallon
10 Well Volumes = 0.4 gallons

Interim Water Characteristics

Gallons Removed 0.5
pH 6.24
Temperature (°C) 20.5
Specific Conductance ~~(µS/cm)~~ 0.589 mS/cm
Dissolved Oxygen (mg/L) 0.8
Redox (mV) -68

Post-Development Information

Time (Finish): 12:45p

Water Level: 13.5

Total Depth of Well: 17.5

Approximate Volume Removed: 1.5 gallons

Water Characteristics
Color Clear (Cloudy)
Odor: None Weak (Moderate) Strong
Any Films or Immiscible Material slight sheen
pH 6.26 Temperature (°C) 21.1
Specific Conductance ~~(µS/cm)~~ 0.585 mS/cm
Dissolved Oxygen (mg/L) 0.5
Redox (mV) -76

Comments:

MONITORING WELL DEVELOPMENT RECORD

Job Number: 722450.37020
Location Shaw AFB
Well Identification MP B

Job Name: AFCEE-RNA
by Cindy Merrill Date: 5/15/97
Measurement Datum TOC 1/2" PVC

Pre-Development Information

Time (Start): 1:00p

Water Level: did not register on Solinst

Total Depth of Well: did not measure Solinst was covered w/ product

Water Characteristics

Color brown globs in GW Clear (Cloudy)
Odor: None Weak Moderate (Strong) fuel
Any Films or Immiscible Material Yes
pH ~~Temperature (°C)~~
Specific Conductance (µS/cm) ~~Not measured because of presence of free product~~
Dissolved Oxygen (mg/L)
Redox (mV)

Interim Water Characteristics

Gallons Removed
pH
Temperature (°C)
Specific Conductance(µS/cm)
Dissolved Oxygen (mg/L)
Redox (mV)

Post-Development Information

Time (Finish): 1:30p

Water Level: Total Depth of Well:

Approximate Volume Removed: 2 gallons

Water Characteristics

Color Clear Cloudy
Odor: None Weak Moderate Strong
Any Films or Immiscible Material
pH Temperature (°C)
Specific Conductance (µS/cm)
Dissolved Oxygen (mg/L)
Redox (mV)

Comments:

MONITORING WELL DEVELOPMENT RECORD

Job Number: 722450.37020
Location Shaw AFB
Well Identification MPC

Job Name: AFCEE-RNA
by Cindy Merrill Date: 5/15/97
Measurement Datum TOC ½"Ø PVC

Pre-Development Information

Time (Start): 8:45a

Water Level: ~~10.27~~ 10.27

Total Depth of Well: 13.62

Water Characteristics
Color (Clear) Cloudy
Odor: None Weak Moderate (Strong) fuel odor
Any Films or Immiscible Material Yes - dark oily immiscible fluid
pH Temperature (°C)
Specific Conductance (µS/cm)
Dissolved Oxygen (mg/L)
Redox (mV)

didn't measure b/c of presence of free-product

Interim Water Characteristics

3.35 ft WC × 0.01 gal/ft WC = 0.033 well volun

Gallons Removed
pH
Temperature (°C)
Specific Conductance(µS/cm)
Dissolved Oxygen (mg/L)
Redox (mV)

10 × 0.0335gal = 0.335 gal Purge Volume

Well did not pump dry at low flow, but when product began to pump out I stopped pumping to allow recharge.

Post-Development Information

Time (Finish): 11:10a

Water Level:

Total Depth of Well: 13.62

Approximate Volume Removed: 2 gallons

Water Characteristics
Color (Clear) Cloudy w/blobs of product
Odor: None Weak Moderate Strong
Any Films or Immiscible Material Yes
pH Temperature (°C)
Specific Conductance (µS/cm)
Dissolved Oxygen (mg/L)
Redox (mV)

Comments: Parameters should be measured during sampling, but we still have background wells to sample & I don't want to risk cross-contamination by sticking the probes in the product & water now.

MONITORING WELL DEVELOPMENT RECORD

Job Number: 722450.37020
Location Shaw AFB
Well Identification MPD

Job Name: AFCEE-RNA
by Cindy Merrill Date: 5/15/97
Measurement Datum TOC

Pre-Development Information

Time (Start): 11:45a

Water Level: 17.21

Total Depth of Well: 22.58

Water Characteristics

Color grey to buff Clear (Cloudy)
Odor: None (Weak) Moderate Strong fuel odor
Any Films or Immiscible ~~Material~~ ~~Sheen~~ slight sheen
pH 5.79 Temperature (°C) 18
Specific Conductance (~~µS/cm~~) 0.035 mS/cm
Dissolved Oxygen (mg/L) 1.2
Redox (mV) -28

Well Vol = 0.0537 gal

10 Well Vols = 0.537 gal

Interim Water Characteristics

Gallons Removed 1.5
pH 5.67
Temperature (°C) 18.6
Specific Conductance(~~µS/cm~~) 0.33 mS/cm
Dissolved Oxygen (mg/L) 1.2
Redox (mV) ~~0~~ -22

Post-Development Information

Time (Finish): 12:00p

Water Level: 19.20

Total Depth of Well: 22.58

Approximate Volume Removed: 2 gallons

Water Characteristics

Color none (Clear) Cloudy
Odor: None (Weak) Moderate Strong fuel odor
Any Films or Immiscible ~~Material~~ slight sheen
pH 5.66 Temperature (°C) 18.3
Specific Conductance (~~µS/cm~~) 0.026
Dissolved Oxygen (mg/L) 0.6
Redox (mV) -28

Comments:

GROUNDWATER SAMPLING RECORD

Sampling Location Shaw AFB
Sampling Dates 5/12/97 - 5/22/97

GROUND WATER SAMPLING RECORD - MONITORING WELL MPA
(Identification)

REASON FOR SAMPLING: [X] Regular Sampling; [ ] Special Sampling;
DATE AND TIME OF SAMPLING: 5/16/97 at 145 a.m./p.m.
SAMPLE COLLECTED BY: TH/CM/CH of Parsons ES
WEATHER: sunny & hot 80°F
DATUM FOR WATER DEPTH MEASUREMENT (Describe): TOC ½" flush mount

MONITORING WELL CONDITION:
[ ] LOCKED: [X] UNLOCKED bolted
WELL NUMBER (IS - IS NOT) APPARENT
STEEL CASING CONDITION IS: Good
INNER PVC CASING CONDITION IS: Good
WATER DEPTH MEASUREMENT DATUM (IS) - IS NOT) APPARENT
[ ] DEFICIENCIES CORRECTED BY SAMPLE COLLECTOR
[ ] MONITORING WELL REQUIRED REPAIR (describe):

Check-off
1 [✓] EQUIPMENT CLEANED BEFORE USE WITH isopropyl, distilled water
Items Cleaned (List): probes

2 [✓] PRODUCT DEPTH NM FT. BELOW DATUM
Measured with: —

WATER DEPTH NM FT. BELOW DATUM
Measured with: —

3 [✓] WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Appearance: silty grey
Odor: ~~fuel~~ strong fuel odor
Other Comments: —

4 [✓] WELL EVACUATION:
Method: peristaltic
Volume Removed:
Observations: Water (slightly - very) cloudy
Water level (rose - fell - no change)
Water odors: strong fuel odor
Other comments: —

Groundwater Sampling Record

Monitoring Well No. MP A (Continued)

5 [M] SAMPLE EXTRACTION METHOD:

[ ] Bailer made of:_____

[X] Pump, type: Peristaltic

[ ] Other, describe:_____

Sample obtained is [X] GRAB; [ ] COMPOSITE SAMPLE

6 [M] ON-SITE MEASUREMENTS:

Time	1:35p	1:40p	1:45p				Measured with
Temp (°C)	19.8	19.7	19.6				YSI 3500
pH	6.05	6.11	6.14				YSI 3500
Cond (mS/cm)	0.592	0.590	0.589				YSI 3500
DO (mg/L)	1.2	0.5	0.5				YSI 51B
Redox (mV)	-33	-47	-56				YSI 3500
gallons purged	0.25	0.5	0.75				5 gallon bucket

7 [M] SAMPLE CONTAINERS (material, number, size): 4 40 ml VOA vials

2 50 ml glass serum bottles

2 125 ml plastic Nalgene bottles

1 250 ml plastic Nalgene bottle

8 [ ] ON-SITE SAMPLE TREATMENT:

[ ] Filtration: Method_____ Containers:_____

Method_____ Containers:_____

Method_____ Containers:_____

[ ] Preservatives added:

Method_____ Containers:_____

Method_____ Containers:_____

Method_____ Containers:_____

Method_____ Containers:_____

9 [ ] CONTAINER HANDLING:

[ ] Container Sides Labeled

[ ] Container Lids Taped

[ ] Containers Placed in Ice Chest

10 [ ] OTHER COMMENTS:_____

GROUNDWATER SAMPLING RECORD

Sampling Location Shaw AFB
Sampling Dates 5/12/97 - 5/22/97

GROUND WATER SAMPLING RECORD - MONITORING WELL MP B
(Identification)

REASON FOR SAMPLING: [X] Regular Sampling; [ ] Special Sampling;
DATE AND TIME OF SAMPLING: 5/16/97 at 330 a.m./(p.m.)
SAMPLE COLLECTED BY: (TH)/CM/CH of Parsons ES
WEATHER: hot & sunny 80°F
DATUM FOR WATER DEPTH MEASUREMENT (Describe): TOC 1/2" ID PVC flush mount

MONITORING WELL CONDITION:
[ ] LOCKED: [X] UNLOCKED bolted cover
WELL NUMBER (IS) - IS NOT) APPARENT
STEEL CASING CONDITION IS: Good
INNER PVC CASING CONDITION IS: Good
WATER DEPTH MEASUREMENT DATUM (IS) - IS NOT) APPARENT
[ ] DEFICIENCIES CORRECTED BY SAMPLE COLLECTOR
[ ] MONITORING WELL REQUIRED REPAIR (describe):

Check-off

1 [✓] EQUIPMENT CLEANED BEFORE USE WITH isopropyl, distilled water
Items Cleaned (List): probes

2 [✓] PRODUCT DEPTH NM No 1/2" oil/water interface FT. BELOW DATUM
Measured with: — probe on site

WATER DEPTH NM pencil probe is not FT. BELOW DATUM
Measured with: — working

3 [✓] WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Appearance: silty grey
Odor: strong fuel odor
Other Comments: —

4 [✓] WELL EVACUATION:
Method: Peristaltic Pump
Volume Removed: 0.75 gal
Observations: Water ((slightly) - very) cloudy
Water level (rose - (fell) - no change)
Water odors: strong fuel odor
Other comments: —

Groundwater Sampling Record

Monitoring Well No. MP B (Continued)

5 [✓] SAMPLE EXTRACTION METHOD:

[ ] Bailer made of:_____
[✓] Pump, type: peristaltic
[ ] Other, describe:_____

Sample obtained is [X] GRAB; [ ] COMPOSITE SAMPLE

6 [ ] ON-SITE MEASUREMENTS:

Time	2:55p	3:10p	3:12p	3:15p	3:22p	3:26p	Measured with
Temp (°C)	20.3	20.1	19.5	19.6	19.6	19.4	YSI 3500
pH	6.07	5.95	5.92	5.94	6.01	6.01	YSI 3500
Cond (µS/cm)	0.088	0.081	0.081	0.075	0.079	0.079	YSI 3500
DO (mg/L)	1.1	1.0	0.4	0.4	0.4	0.3	YSI ~~51~~ B
Redox (mV)	46	41	24	6	-33	-35	YSI 3500
gallons purged	0.25	0.35	0.4	0.45	0.5	0.55	5 gal bucket

7 [✓] SAMPLE CONTAINERS (material, number, size): 4 40ml VOA vials
2 50ml glass serum bottles
2 125 ml ~~glass~~ plastic Nalgene bottles
(CN) 1 250 ml plastic Nalgene bottle
1 product sample

8 [ ] ON-SITE SAMPLE TREATMENT:

[ ] Filtration: Method_____ Containers:_____
Method_____ Containers:_____
Method_____ Containers:_____

[ ] Preservatives added:

Method_____ Containers:_____
Method_____ Containers:_____
Method_____ Containers:_____
Method_____ Containers:_____

9 [ ] CONTAINER HANDLING:

[ ] Container Sides Labeled
[ ] Container Lids Taped
[ ] Containers Placed in Ice Chest

10 [✓] OTHER COMMENTS: EPA handled samples.

GROUNDWATER SAMPLING RECORD

Sampling Location Shaw AFB
Sampling Dates 5/12/97 - 5/22/97

GROUND WATER SAMPLING RECORD - MONITORING WELL MPC
(Identification)

REASON FOR SAMPLING: [X] Regular Sampling; [ ] Special Sampling;
DATE AND TIME OF SAMPLING: 5/16/97 at 10:30 a.m./p.m.
SAMPLE COLLECTED BY: TH/CM/CH of Parsons ES
WEATHER: clear, 70°F
DATUM FOR WATER DEPTH MEASUREMENT (Describe): TOC 1/2"Ø flush mount

MONITORING WELL CONDITION:
LOCKED: [X] UNLOCKED bolted
WELL NUMBER (IS - IS NOT) APPARENT
STEEL CASING CONDITION IS: Good
INNER PVC CASING CONDITION IS: Good
WATER DEPTH MEASUREMENT DATUM (IS - IS NOT) APPARENT
[ ] DEFICIENCIES CORRECTED BY SAMPLE COLLECTOR
[ ] MONITORING WELL REQUIRED REPAIR (describe):

Check-off

1 [X] EQUIPMENT CLEANED BEFORE USE WITH isopropyl, distilled water
Items Cleaned (List): probes

2 [X] PRODUCT DEPTH NM FT. BELOW DATUM
Measured with: (No oil/water interface probe small enough)
WATER DEPTH NM estimated ~10' FT. BELOW DATUM
Measured with: (neither Solinst is working)

3 [X] WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Appearance: silty grey
Odor: none
Other Comments: —

4 [X] WELL EVACUATION:
Method: Peristaltic Pump
Volume Removed: ~1 gallon
Observations: Water (slightly / very) cloudy
Water level (rose / fell / no change)
Water odors: none
Other comments: —

Groundwater Sampling Record

Monitoring Well No. MPC (Continued)

5 [✓] SAMPLE EXTRACTION METHOD:

[ ] Bailer made of: _____
[X] Pump, type: Peristaltic
[ ] Other, describe: _____

Sample obtained is [X] GRAB; [ ] COMPOSITE SAMPLE

6 [✓] ON-SITE MEASUREMENTS:

Time	10:20a	10:27a	10:30a				Measured with
Temp (°C)	17.2	17.2	17.4				YSI 3500
pH	4.99	5.02	5.04				YSI 3500
Cond (µS/cm)	0.065	0.060	0.035				YSI 3500
DO (mg/L)	1.2	0.8	0.5				YSI 51B
Redox (mV)	61	56	58				YSI 3500
gallons purged	0.25	0.5	0.75				5 gallon bucket

7 [✓] SAMPLE CONTAINERS (material, number, size): 4 40ml VOA vials
2 50ml glass serum bottles
2 125ml plastic bottles
1 250ml plastic bottles
1 product sample

8 [ ] ON-SITE SAMPLE TREATMENT:

[ ] Filtration: Method _____ Containers: _____
Method _____ Containers: _____
Method _____ Containers: _____

[ ] Preservatives added:

Method _____ Containers: _____
Method _____ Containers: _____
Method _____ Containers: _____
Method _____ Containers: _____

9 [ ] CONTAINER HANDLING:

[ ] Container Sides Labeled
[ ] Container Lids Taped
[ ] Containers Placed in Ice Chest

10 [✓] OTHER COMMENTS: EPA handled samples

GROUNDWATER SAMPLING RECORD

Sampling Location Shaw AFB
Sampling Dates 5/12/97 - 5/22/97

GROUND WATER SAMPLING RECORD - MONITORING WELL MP D
(Identification)

REASON FOR SAMPLING: [X] Regular Sampling; [ ] Special Sampling;
DATE AND TIME OF SAMPLING: 5/16/97 at 1:15 a.m./p.m.
SAMPLE COLLECTED BY: TH/CM/CH of Parsons ES
WEATHER: sunny 80°F
DATUM FOR WATER DEPTH MEASUREMENT (Describe): TOC ½" flush mount

MONITORING WELL CONDITION:
[ ] LOCKED: [X] UNLOCKED but bolted
WELL NUMBER (IS - IS NOT) APPARENT
STEEL CASING CONDITION IS: Good
INNER PVC CASING CONDITION IS: Good
WATER DEPTH MEASUREMENT DATUM (IS - IS NOT) APPARENT
[ ] DEFICIENCIES CORRECTED BY SAMPLE COLLECTOR
[ ] MONITORING WELL REQUIRED REPAIR (describe):

Check-off
1 [✓] EQUIPMENT CLEANED BEFORE USE WITH isopropyl, distilled water
Items Cleaned (List): probes

2 [✓] PRODUCT DEPTH NA FT. BELOW DATUM
Measured with: —

WATER DEPTH NM water level meter FT. BELOW DATUM
Measured with: — is no longer working - see development record for previous measurement

3 [✓] WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Appearance: silty, grey
Odor: none
Other Comments: —

4 [✓] WELL EVACUATION:
Method: peristaltic pump
Volume Removed: ~½ gallon
Observations: Water (slightly - very) cloudy
Water level (rose - fell - no change)
Water odors: none
Other comments: —

Groundwater Sampling Record

Monitoring Well No. MPD (Continued)

5 [✓] SAMPLE EXTRACTION METHOD:

[ ] Bailer made of:_____
[✓] Pump, type: Peristaltic
[ ] Other, describe:_____

Sample obtained is [X] GRAB; [ ] COMPOSITE SAMPLE

6 [✓] ON-SITE MEASUREMENTS:

Time	12:57p	1:00p	1:03p	1:06p			Measured with
Temp (°C)	18.4	18.1	18.1	18.1			YSI 3500
pH	5.73	5.64	5.61	5.60			YSI 3500
Cond (mS/cm)	0.042	0.032	0.041	0.043			YSI 3500
DO (mg/L)	0.7	0.6	0.5	0.5			YSI 51B
Redox (mV)	52	34	26	25			YSI 3500
gallons purged	<0.25	0.25	0.25-0.5	0.5			5 gallon bucket

7 [✓] SAMPLE CONTAINERS (material, number, size): 4 40 ml VOA vials
2 50 ml glass serum bottles
2 125 ml plastic Nalgene bottles
(2) 1 250 ml plastic Nalgene bottle

8 [ ] ON-SITE SAMPLE TREATMENT:

[ ] Filtration: Method_____ Containers:_____
Method_____ Containers:_____
Method_____ Containers:_____

[ ] Preservatives added:

Method_____ Containers:_____
Method_____ Containers:_____
Method_____ Containers:_____
Method_____ Containers:_____

9 [ ] CONTAINER HANDLING:

[ ] Container Sides Labeled
[ ] Container Lids Taped
[ ] Containers Placed in Ice Chest

10 [✓] OTHER COMMENTS: EPA handled samples

GROUNDWATER SAMPLING RECORD

Sampling Location Shaw AFB
Sampling Dates 5/12/97 - 5/22/97

GROUND WATER SAMPLING RECORD - MONITORING WELL MPE
(Identification)

REASON FOR SAMPLING: [X] Regular Sampling; [ ] Special Sampling;
DATE AND TIME OF SAMPLING: 5/17/97 at 8:45 (a.m.)/p.m.
SAMPLE COLLECTED BY: TH/(CM)/CH of Parsons ES
WEATHER: clear & breezy 55°F
DATUM FOR WATER DEPTH MEASUREMENT (Describe): Not measured 1/4" ID tubing w/ stainless steel point @ 20' bgs

MONITORING WELL CONDITION:
[ ] LOCKED: [ ] UNLOCKED
WELL NUMBER (IS - IS NOT) APPARENT
STEEL CASING CONDITION IS: NA
INNER PVC CASING CONDITION IS:
WATER DEPTH MEASUREMENT DATUM (IS - IS NOT) APPARENT
[ ] DEFICIENCIES CORRECTED BY SAMPLE COLLECTOR
[ ] MONITORING WELL REQUIRED REPAIR (describe):

Check-off
1 [✓] EQUIPMENT CLEANED BEFORE USE WITH isopropyl, distilled water
Items Cleaned (List): probes

2 [✓] PRODUCT DEPTH ____ FT. BELOW DATUM
Measured with:
WATER DEPTH Not Measured FT. BELOW DATUM
Measured with:

3 [✓] WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Appearance: silty, grey
Odor: none
Other Comments: —

4 [✓] WELL EVACUATION:
Method: Peristaltic
Volume Removed:
Observations: Water (slightly) - very) cloudy
Water level (rose - (fell) - no change)
Water odors: none
Other comments: —

Groundwater Sampling Record

Monitoring Well No. MPE (Continued)

5 [✓] SAMPLE EXTRACTION METHOD:

[ ] Bailer made of:_____
[✓] Pump, type: Peristaltic
[ ] Other, describe:_____

Sample obtained is [X] GRAB; [ ] COMPOSITE SAMPLE

6 [✓] ON-SITE MEASUREMENTS:

Time	815a	820a	830a	835a	840a		Measured with
Temp (°C)	16.4	16.5	16.7	16.6	16.6		YSI 3500
pH	7.13	6.90	6.63	6.50	6.42		YSI 3500
Cond (mS/cm) → mS/cm	0.081	0.068	0.060	0.060	0.058		YSI 3500
DO (mg/L)	1.0	0.8	0.5	0.4	0.4		YSI 51B
Redox (mV)	-33	-27	-13	-10	-7		YSI 3500
gallons purged	1/10	2/10	3/10	4/10	0.5		5 gallon bucket

7 [✓] SAMPLE CONTAINERS (material, number, size): 4 40ml VOA vials
2 50ml glass serum bottles
2 125ml plastic Nalgene bottles
1 250ml plastic Nalgene bottles

8 [ ] ON-SITE SAMPLE TREATMENT:

[ ] Filtration: Method_____ Containers:_____
Method_____ Containers:_____
Method_____ Containers:_____

[ ] Preservatives added:

Method_____ Containers:_____
Method_____ Containers:_____
Method_____ Containers:_____
Method_____ Containers:_____

9 [ ] CONTAINER HANDLING:

[ ] Container Sides Labeled
[ ] Container Lids Taped
[ ] Containers Placed in Ice Chest

10 [✓] OTHER COMMENTS: EPA handled samples

GROUNDWATER SAMPLING RECORD

Sampling Location Shaw AFB
Sampling Dates 5/12/97 - 5/22/97

GROUND WATER SAMPLING RECORD - MONITORING WELL TMP-1
(Identification)

REASON FOR SAMPLING: [X] Regular Sampling; [ ] Special Sampling;
DATE AND TIME OF SAMPLING: 5/19 at 11:04 (a.m.) p.m.
SAMPLE COLLECTED BY: TH/CM/CH of Parsons ES
WEATHER: sunny ~70°
DATUM FOR WATER DEPTH MEASUREMENT (Describe):

MONITORING WELL CONDITION:
[ ] LOCKED: [ ] UNLOCKED
WELL NUMBER (IS - IS NOT) APPARENT
STEEL CASING CONDITION IS:
INNER PVC CASING CONDITION IS:
WATER DEPTH MEASUREMENT DATUM (IS - IS NOT) APPARENT
[ ] DEFICIENCIES CORRECTED BY SAMPLE COLLECTOR
[ ] MONITORING WELL REQUIRED REPAIR (describe):

Check-off
1 [ ] EQUIPMENT CLEANED BEFORE USE WITH dedicated
Items Cleaned (List):

2 [ ] PRODUCT DEPTH NA FT. BELOW DATUM
Measured with:

WATER DEPTH NA FT. BELOW DATUM
Measured with:

3 [ ] WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Appearance:
Odor:
Other Comments:

4 [ ] WELL EVACUATION:
Method: Peristaltic
Volume Removed:
Observations: Water (slightly - very) cloudy
Water level (rose - fell - no change)
Water odors: none
Other comments:

Groundwater Sampling Record

Monitoring Well No. MP-1 (Continued)

5 [ ] SAMPLE EXTRACTION METHOD:

[ ] Bailer made of: peristaltic
[ ] Pump, type: _____
[ ] Other, describe: _____

Sample obtained is [X] GRAB; [ ] COMPOSITE SAMPLE

6 [ ] ON-SITE MEASUREMENTS:

Time	11:08	11:12	11:16	11:23	11:29		Measured with
Temp (°C)	17.1	17.0	17.0	17.0	17.1		
pH	4.3	4.3	4.3	4.3	4.3		
Cond (µS/cm)	20	20	20	20	19		
DO (mg/L)	2.3	2.6	2.7	2.7	3.0		
Redox (mV)	245	250	235	260	260		
gallons purged	≈ 1/2 gal	—	—	→	2 gal		

7 [ ] SAMPLE CONTAINERS (material, number, size):
4 VOAs
2 125-mLs w/acid
2 serum w/acid
1 250-mL vial

8 [ ] ON-SITE SAMPLE TREATMENT:

[ ] Filtration: Method _____ Containers: _____
Method _____ Containers: _____
Method _____ Containers: _____

[ ] Preservatives added:

Method _____ Containers: _____
Method _____ Containers: _____
Method _____ Containers: _____
Method _____ Containers: _____

9 [ ] CONTAINER HANDLING:

[ ] Container Sides Labeled
[ ] Container Lids Taped
[ ] Containers Placed in Ice Chest

10 [ ] OTHER COMMENTS: purged OK

GROUNDWATER SAMPLING RECORD

Sampling Location Shaw AFB
Sampling Dates 5/12/97 - 5/22/97

GROUND WATER SAMPLING RECORD - MONITORING WELL TMP-2
(Identification)

REASON FOR SAMPLING: [X] Regular Sampling; [ ] Special Sampling;
DATE AND TIME OF SAMPLING: 5/17/97 at 2:15 a.m./p.m.
SAMPLE COLLECTED BY: TH/CM/CH of Parsons ES
WEATHER: Sunny ~70
DATUM FOR WATER DEPTH MEASUREMENT (Describe):

MONITORING WELL CONDITION:

[ ] LOCKED: [ ] UNLOCKED
WELL NUMBER (IS - IS NOT) APPARENT
STEEL CASING CONDITION IS:
INNER PVC CASING CONDITION IS:
WATER DEPTH MEASUREMENT DATUM (IS - IS NOT) APPARENT
[ ] DEFICIENCIES CORRECTED BY SAMPLE COLLECTOR
[ ] MONITORING WELL REQUIRED REPAIR (describe):

Check-off

1 [ ] EQUIPMENT CLEANED BEFORE USE WITH
Items Cleaned (List):

2 [ ] PRODUCT DEPTH FT. BELOW DATUM
Measured with:

WATER DEPTH FT. BELOW DATUM
Measured with:

3 [ ] WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Appearance:
Odor:
Other Comments:

4 [ ] WELL EVACUATION:
Method:
Volume Removed:
Observations: Water (slightly - very) cloudy
Water level (rose - fell - no change)
Water odors:
Other comments:

Groundwater Sampling Record

Monitoring Well No. TMP-2 (Continued)

5 [ ] SAMPLE EXTRACTION METHOD:

[ ] Bailer made of:
[✓] Pump, type: peristaltic
[ ] Other, describe:

Sample obtained is [X] GRAB; [ ] COMPOSITE SAMPLE

6 [ ] ON-SITE MEASUREMENTS:

Time	14:16	14:20	14:23	14:25			Measured with
Temp (°C)	18.4	17.9	17.9	17.8			
pH	5.0	5.1	5.1	5.1			
Cond (µS/cm)	58	57	57	57			
DO (mg/L)	0.3	0.4	0.1	0.2			
Redox (mV)	-5	-15	-15	-20			
gallons purged	~1/2 gal	~1 gal	~1 1/4 gal	~1 1/2 gal			

7 [ ] SAMPLE CONTAINERS (material, number, size):
4 VOAs
2 125-mL (w/acid)
4 syrum (w/acid)
1 250-mL

8 [ ] ON-SITE SAMPLE TREATMENT:

[ ] Filtration: Method____ Containers:____
Method____ Containers:____
Method____ Containers:____

[ ] Preservatives added:

Method____ Containers:____
Method____ Containers:____
Method____ Containers:____
Method____ Containers:____

9 [ ] CONTAINER HANDLING:

[ ] Container Sides Labeled
[ ] Container Lids Taped
[ ] Containers Placed in Ice Chest

10 [ ] OTHER COMMENTS:

GROUNDWATER SAMPLING RECORD

Sampling Location Shaw AFB
Sampling Dates 5/12/97 - 5/22/97

GROUND WATER SAMPLING RECORD - MONITORING WELL TMP3
(Identification)

REASON FOR SAMPLING: [X] Regular Sampling; [ ] Special Sampling;
DATE AND TIME OF SAMPLING: 5-17-97 at 9:56 (a.m.)/p.m.
SAMPLE COLLECTED BY: (TH)CM/(CH) of Parsons ES
WEATHER: Sunny ~ 70
DATUM FOR WATER DEPTH MEASUREMENT (Describe):

MONITORING WELL CONDITION: SS paint
[ ] LOCKED: [ ] UNLOCKED
WELL NUMBER (IS - IS NOT) APPARENT
STEEL CASING CONDITION IS:
INNER PVC CASING CONDITION IS:
WATER DEPTH MEASUREMENT DATUM (IS - IS NOT) APPARENT
[ ] DEFICIENCIES CORRECTED BY SAMPLE COLLECTOR
[ ] MONITORING WELL REQUIRED REPAIR (describe):

Check-off

1 [ ] EQUIPMENT CLEANED BEFORE USE WITH Dedicated
Items Cleaned (List):

2 [ ] PRODUCT DEPTH NA FT. BELOW DATUM
Measured with:

WATER DEPTH NA FT. BELOW DATUM
Measured with:

3 [ ] WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Appearance:
Odor:
Other Comments:

4 [ ] WELL EVACUATION:
Method: Peristaltic
Volume Removed:
Observations: Water (slightly (very) cloudy
Water level (rose - fell - no change)
Water odors: None apparent
Other comments:

Groundwater Sampling Record

Monitoring Well No. MP-3 (Continued)

5 [ ] SAMPLE EXTRACTION METHOD:

[ ] Bailer made of: Peristaltic
[ ] Pump, type:
[ ] Other, describe:

Sample obtained is [X] GRAB; [ ] COMPOSITE SAMPLE

6 [ ] ON-SITE MEASUREMENTS:

Time	10:04	10:09	10:14	10:16			Measured with
Temp (°C)	16.6	16.5	16.5	16.5			
pH	4.5	4.5	4.5	4.6			
Cond (µS/cm)	39	39	39	40			
DO (mg/L)	0.2	0.2	0.3	0.2			
Redox (mV)	195	230	250	255			
gallons purged	≈ 1/2 gal	→	→	2 gal			

Purging ≈ 200 mL/min.

7 [ ] SAMPLE CONTAINERS (material, number, size):
4 VOA's
2 125 mL's with Acid
2 Serum with Acid
1 250 mL Vial.

8 [ ] ON-SITE SAMPLE TREATMENT:

[ ] Filtration: Method____ Containers:____
Method____ Containers:____
Method____ Containers:____

[ ] Preservatives added:

Method____ Containers:____
Method____ Containers:____
Method____ Containers:____
Method____ Containers:____

9 [ ] CONTAINER HANDLING:

[ ] Container Sides Labeled
[ ] Container Lids Taped
[ ] Containers Placed in Ice Chest

10 [ ] OTHER COMMENTS: Purged ok.

GROUNDWATER SAMPLING RECORD

Sampling Location Shaw AFB
Sampling Dates 5/12/97 - 5/22/97

GROUND WATER SAMPLING RECORD - MONITORING WELL TMP-4
(Identification)

REASON FOR SAMPLING: [X] Regular Sampling; [ ] Special Sampling;
DATE AND TIME OF SAMPLING: 5/16 at 15:53 a.m./p.m.
SAMPLE COLLECTED BY: (TH/CM/CH) of (Parsons ES)
WEATHER: Sunny
DATUM FOR WATER DEPTH MEASUREMENT (Describe):

MONITORING WELL CONDITION:
[ ] LOCKED: [ ] UNLOCKED
SS Point WELL NUMBER (IS - IS NOT) APPARENT
STEEL CASING CONDITION IS:
INNER PVC CASING CONDITION IS:
WATER DEPTH MEASUREMENT DATUM (IS - IS NOT) APPARENT
[ ] DEFICIENCIES CORRECTED BY SAMPLE COLLECTOR
[ ] MONITORING WELL REQUIRED REPAIR (describe):

Check-off
1 [ ] EQUIPMENT CLEANED BEFORE USE WITH dedicated
Items Cleaned (List):

2 [ ] PRODUCT DEPTH NA FT. BELOW DATUM
Measured with:

WATER DEPTH FT. BELOW DATUM
Measured with:

3 [ ] WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Appearance: mucky gray
Odor:
Other Comments:

4 [ ] WELL EVACUATION:
Method: peristaltic pump
Volume Removed: ~10 L
Observations: Water (slightly - very) cloudy
Water level (rose - fell - no change)
Water odors:
Other comments:

Groundwater Sampling Record

Monitoring Well No. TMP-4 (Continued)

5 [ ] SAMPLE EXTRACTION METHOD:

[ ] Bailer made of:_____
[X] Pump, type: peristaltic
[ ] Other, describe:_____

Sample obtained is [X] GRAB; [ ] COMPOSITE SAMPLE

6 [ ] ON-SITE MEASUREMENTS:

Time	15:58	16:04	16:07				Measured with
Temp (°C)	17.7	17.2	17.2				
pH	4.4	4.3	4.3				
Cond (µS/cm)	69	71	72				
DO (mg/L)	0.1	0	0				
Redox (mV)	5	-5	-5				
gallons purged	≈ 1/2 gal	→	2 gal				

7 [ ] SAMPLE CONTAINERS (material, number, size):

4 40-mL VOA
2 125-mL Plastic (w/ acid)
2 Serum (w/ acid)
1 250-mL

8 [ ] ON-SITE SAMPLE TREATMENT:

[ ] Filtration: Method_____ Containers:_____
Method_____ Containers:_____
Method_____ Containers:_____

[ ] Preservatives added:

Method_____ Containers:_____
Method_____ Containers:_____
Method_____ Containers:_____
Method_____ Containers:_____

9 [ ] CONTAINER HANDLING:

[ ] Container Sides Labeled
[ ] Container Lids Taped
[ ] Containers Placed in Ice Chest

10 [ ] OTHER COMMENTS:_____

GROUNDWATER SAMPLING RECORD

Sampling Location Shaw AFB
Sampling Dates 5/12/97 - 5/22/97

GROUND WATER SAMPLING RECORD - MONITORING WELL TMP-5
(Identification)

REASON FOR SAMPLING: [X] Regular Sampling; [ ] Special Sampling;
DATE AND TIME OF SAMPLING: 5/16 at 14:37 a.m./p.m.
SAMPLE COLLECTED BY: ~~THEMCH~~ of Parsons ES
WEATHER: sunny
DATUM FOR WATER DEPTH MEASUREMENT (Describe):

MONITORING WELL CONDITION:
[ ] LOCKED: [ ] UNLOCKED
SS Point WELL NUMBER (IS - IS NOT) APPARENT
STEEL CASING CONDITION IS:
INNER PVC CASING CONDITION IS:
WATER DEPTH MEASUREMENT DATUM (IS - IS NOT) APPARENT
[ ] DEFICIENCIES CORRECTED BY SAMPLE COLLECTOR
[ ] MONITORING WELL REQUIRED REPAIR (describe):

Check-off
1 [ ] EQUIPMENT CLEANED BEFORE USE WITH dedicated
Items Cleaned (List):

2 [ ] PRODUCT DEPTH N/A FT. BELOW DATUM
Measured with:

WATER DEPTH FT. BELOW DATUM
Measured with:

3 [ ] WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Appearance: slightly muddy / brown
Odor:
Other Comments: air in line while pumping

4 [ ] WELL EVACUATION:
Method: peristaltic pump
Volume Removed: ~10L
Observations: Water (slightly - very) cloudy
Water level (rose - fell - no change)
Water odors:
Other comments:

Groundwater Sampling Record

Monitoring Well No. TMP-5 (Continued)

5 [ ] SAMPLE EXTRACTION METHOD:

[ ] Bailer made of:_____
[✓] Pump, type: peristaltic
[ ] Other, describe:_____

Sample obtained is [X] GRAB; [ ] COMPOSITE SAMPLE

6 [ ] ON-SITE MEASUREMENTS:

Time	14:40	14:45	14:50	14:52	1500		Measured with
Temp (°C)	16.3	16.3	16.3	16.2	16.2		
pH			4.5	4.3	4.4		
Cond (µS/cm)			48	47	47		
DO (mg/L)	0.4	0.1	0.2	0.1	0.1		
Redox (mV)			-20	-20	-30		
gallons purged	1 1/2 gal				3 gal		

7 [ ] SAMPLE CONTAINERS (material, number, size):

4 VOA (40-mL)
2 125-mL Plastic (acid)
2 Serum (w/acid)
1 250-mL Plastic

8 [ ] ON-SITE SAMPLE TREATMENT:

[ ] Filtration: Method_____ Containers:_____
Method_____ Containers:_____
Method_____ Containers:_____

[ ] Preservatives added:

Method_____ Containers:_____
Method_____ Containers:_____
Method_____ Containers:_____
Method_____ Containers:_____

9 [ ] CONTAINER HANDLING:

[ ] Container Sides Labeled
[ ] Container Lids Taped
[ ] Containers Placed in Ice Chest

10 [ ] OTHER COMMENTS:_____

GROUNDWATER SAMPLING RECORD

Sampling Location Shaw AFB
Sampling Dates 5/12/97 - 5/22/97

GROUND WATER SAMPLING RECORD - MONITORING WELL FW 101
(Identification)

REASON FOR SAMPLING: [X] Regular Sampling; [ ] Special Sampling;
DATE AND TIME OF SAMPLING: 5/14/97 at 14:40 a.m./p.m.
SAMPLE COLLECTED BY: ~~TH/CM/CH of Parsons ES~~ DK of FB EPA
WEATHER: Partly Cloudy & slight Breeze
DATUM FOR WATER DEPTH MEASUREMENT (Describe): 18.70

MONITORING WELL CONDITION:
[ ] LOCKED: [X] UNLOCKED
WELL NUMBER (IS - IS NOT) APPARENT
STEEL CASING CONDITION IS: Rusty
INNER PVC CASING CONDITION IS: good
WATER DEPTH MEASUREMENT DATUM (IS - IS NOT) APPARENT
[ ] DEFICIENCIES CORRECTED BY SAMPLE COLLECTOR
[ ] MONITORING WELL REQUIRED REPAIR (describe):

Check-off

1 [ ] EQUIPMENT CLEANED BEFORE USE WITH
Items Cleaned (List):

2 [ ] PRODUCT DEPTH 1' FT. BELOW DATUM
Measured with:

WATER DEPTH 18.7 FT. BELOW DATUM
Measured with: water probe

3 [ ] WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Appearance: too deep to see
Odor: none
Other Comments:

4 [ ] WELL EVACUATION:
Method: Model ES 40 DC Pump
Volume Removed: 35 gal
Observations: Water (slightly - (very) cloudy
Water level (rose - fell - no change)
Water odors: none
Other comments: iron flocculants in early purge water
Cleared up at about 10 gal.

Groundwater Sampling Record

Monitoring Well No. TW 101 (Continued)

5 [ ] SAMPLE EXTRACTION METHOD:

[ ] Bailer made of:_____
[X] Pump, type: Cole Parmer tubing pump
[ ] Other, describe:_____

Sample obtained is [X] GRAB; [ ] COMPOSITE SAMPLE

6 [ ] ON-SITE MEASUREMENTS:

Time	1343	1453	1504	1514			Measured with
Temp (°C)	23.1	22.9	22.6	21.8			
pH	6.37	6.23	6.21	6.22			
Cond (µS/cm)	132.4	128.7	125.6	124.4			
DO (mg/L)	4.9	4.6	4.0	4.1			
Redox (mV)	66.4	66.7	71.0	74.0			
gallons purged	35.5	36	36.5	37.0			

7 [ ] SAMPLE CONTAINERS (material, number, size):_____

8 [ ] ON-SITE SAMPLE TREATMENT:

[ ] Filtration: Method_____ Containers:_____
Method_____ Containers:_____
Method_____ Containers:_____

[ ] Preservatives added:

Method_____ Containers:_____
Method_____ Containers:_____
Method_____ Containers:_____
Method_____ Containers:_____

9 [ ] CONTAINER HANDLING:

[ ] Container Sides Labeled
[ ] Container Lids Taped
[ ] Containers Placed in Ice Chest

10 [ ] OTHER COMMENTS:_____

GROUNDWATER SAMPLING RECORD

Sampling Location Shaw AFB
Sampling Dates 5/12/97 - 5/22/97

GROUND WATER SAMPLING RECORD - MONITORING WELL TW-120
(Identification)

REASON FOR SAMPLING: [X] Regular Sampling; [ ] Special Sampling;
DATE AND TIME OF SAMPLING: 5/17 at 11:52 a.m./p.m.
SAMPLE COLLECTED BY: ~~FH/CM/CB~~ of Parsons ES
WEATHER: Sunny ~ 70°
DATUM FOR WATER DEPTH MEASUREMENT (Describe): ground surface (PVC flush w/ ground)

MONITORING WELL CONDITION:
[ ] LOCKED: [ ] UNLOCKED
WELL NUMBER (IS - IS NOT) APPARENT
STEEL CASING CONDITION IS:
INNER PVC CASING CONDITION IS:
WATER DEPTH MEASUREMENT DATUM (IS - IS NOT) APPARENT
[ ] DEFICIENCIES CORRECTED BY SAMPLE COLLECTOR
[ ] MONITORING WELL REQUIRED REPAIR (describe):

Check-off

1 [ ] EQUIPMENT CLEANED BEFORE USE WITH
Items Cleaned (List):

2 [ ] PRODUCT DEPTH FT. BELOW DATUM
Measured with:

WATER DEPTH 5" FT. BELOW DATUM
Measured with: tape measure

3 [ ] WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Appearance:
Odor:
Other Comments:

4 [ ] WELL EVACUATION:
Method:
Volume Removed:
Observations: Water (slightly - very) cloudy
Water level (rose - fell - no change)
Water odors: none
Other comments:

Note: Well depth = 5'4"

Groundwater Sampling Record

Monitoring Well No. TW-120 (Continued)

5 [ ] SAMPLE EXTRACTION METHOD:

[~~X~~] Bailer made of: ~~Plastic~~

[✓] Pump, type: Peristaltic

[ ] Other, describe: _____

Sample obtained is [X] GRAB; [ ] COMPOSITE SAMPLE

6 [ ] ON-SITE MEASUREMENTS: pumped dry

Time	1202	12:08					Measured with
Temp (°C)	16.7	16.6					ORION
pH	4.9	4.9					hand-meter
Cond (µS/cm)	54	57					ORION
DO (mg/L)	0.0	0.3					ORION
Redox (mV)	60	60					hand-meter
gallons purged	≈ 1¼ gal.	≈ 1 gal					

7 [ ] SAMPLE CONTAINERS (material, number, size):

4 40-mL VOA (w/ preservative)

~~2 125-mL Plastic (w/ acid)~~

~~2 Semm (w/ acid)~~

~~1 250-mL~~

8 [ ] ON-SITE SAMPLE TREATMENT:

[ ] Filtration: Method_____ Containers:_____
Method_____ Containers:_____
Method_____ Containers:_____

[ ] Preservatives added:

Method_____ Containers:_____
Method_____ Containers:_____
Method_____ Containers:_____
Method_____ Containers:_____

9 [ ] CONTAINER HANDLING:

[ ] Container Sides Labeled
[ ] Container Lids Taped
[ ] Containers Placed in Ice Chest

10 [ ] OTHER COMMENTS: purged dry at 12:10pm after just over one gallon (on lowest pumping rate)
recharge rate is approx. 50-mL every 5 min

Note: Only filled 4 VOA bottles since well went dry after 30 sec of pumping (samples were muddy)

GROUNDWATER SAMPLING RECORD

Sampling Location Shaw AFB
Sampling Dates 5/12/97 - 5/22/97

GROUND WATER SAMPLING RECORD - MONITORING WELL TW-121
(Identification)

REASON FOR SAMPLING: [X] Regular Sampling; [ ] Special Sampling;
DATE AND TIME OF SAMPLING: 5/17 at 8:44 a.m./p.m.
SAMPLE COLLECTED BY: TH/CM/CH of Parsons ES
WEATHER: sunny
DATUM FOR WATER DEPTH MEASUREMENT (Describe): t.o.p. of 2" PVC (4" ags)

MONITORING WELL CONDITION:
[Y] LOCKED: [ ] UNLOCKED
WELL NUMBER (IS - IS NOT) APPARENT
STEEL CASING CONDITION IS:
INNER PVC CASING CONDITION IS:
WATER DEPTH MEASUREMENT DATUM (IS - IS NOT) APPARENT
[ ] DEFICIENCIES CORRECTED BY SAMPLE COLLECTOR
[ ] MONITORING WELL REQUIRED REPAIR (describe):

Check-off

1 [ ] EQUIPMENT CLEANED BEFORE USE WITH
Items Cleaned (List):

2 [ ] PRODUCT DEPTH FT. BELOW DATUM
Measured with:

WATER DEPTH 8 7/8" bte FT. BELOW DATUM
Measured with: measuring tape

3 [ ] WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Appearance:
Odor:
Other Comments:

4 [ ] WELL EVACUATION:
Method:
Volume Removed:
Observations: Water (slightly - very) cloudy
Water level (rose - fell - no change)
Water odors:
Other comments:

Note: used ~~tubing from TMP-4 to do the purging~~ CH
well depth = 5 ft

Groundwater Sampling Record

Monitoring Well No. TW-121 (Continued)

5 [ ] SAMPLE EXTRACTION METHOD:

[ ] Bailer made of:
[✓] Pump, type: peristaltic
[ ] Other, describe:

Sample obtained is [X] GRAB; [ ] COMPOSITE SAMPLE

6 [ ] ON-SITE MEASUREMENTS: Probably of influence from over purging. Pumped Dry.

Time	9:02	9:07	9:10	9:21	9:26	9:29	Measured with
Temp (°C)	17.1	17.0		17.1	17.1	17.1	
pH	6.1	6.1		6.0	2.1	6.1	small pH tester
Cond (µS/cm)	254	306	329	342	354	353	
DO (mg/L)	0.2	5.2	6.7	4.7	2.9	3.1	
Redox (mV)	-65	-75		-60	-65	-65	small ORP Tester
gallons purged	~1		~2 tot.				

- Well Pumped Dry

sample

7 [ ] SAMPLE CONTAINERS (material, number, size):

8 [ ] ON-SITE SAMPLE TREATMENT:

[ ] Filtration: Method Containers:
Method Containers:
Method Containers:

[ ] Preservatives added:

Method Containers:
Method Containers:
Method Containers:
Method Containers:

9 [ ] CONTAINER HANDLING:

[ ] Container Sides Labeled
[ ] Container Lids Taped
[ ] Containers Placed in Ice Chest

10 [ ] OTHER COMMENTS: Well purged Dry after ~2 gallons - Wait for [illegible] & pump @ slower rate.

GROUNDWATER SAMPLING RECORD

Sampling Location Shaw AFB
Sampling Dates 5/12/97 - 5/22/97

GROUND WATER SAMPLING RECORD - MONITORING WELL MW 105
(Identification)

REASON FOR SAMPLING: [X] Regular Sampling; [ ] Special Sampling;
DATE AND TIME OF SAMPLING: 5/15/97 at 0800 a.m./p.m.
SAMPLE COLLECTED BY: ~~AW/CW/CH of Parsons ES~~ DK & FB of EPA
WEATHER: Clear warm
DATUM FOR WATER DEPTH MEASUREMENT (Describe): 13.46' from black mark on casing

MONITORING WELL CONDITION:
[ ] LOCKED: [X] UNLOCKED
WELL NUMBER (IS - IS NOT) APPARENT
STEEL CASING CONDITION IS: good
INNER PVC CASING CONDITION IS: good
WATER DEPTH MEASUREMENT DATUM (IS - IS NOT) APPARENT
[ ] DEFICIENCIES CORRECTED BY SAMPLE COLLECTOR
[ ] MONITORING WELL REQUIRED REPAIR (describe):

Check-off

1 [ ] EQUIPMENT CLEANED BEFORE USE WITH used new tubing
Items Cleaned (List):

2 [ ] PRODUCT DEPTH _____ FT. BELOW DATUM
Measured with:

WATER DEPTH 13.46' FT. BELOW DATUM
Measured with: water probe

3 [ ] WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Appearance: cloudy (white) with debris in water
Odor: non observable
Other Comments:

4 [ ] WELL EVACUATION:
Method: peristaltic pump
Volume Removed:
Observations: Water (slightly - very) cloudy
Water level (rose - fell - no change)
Water odors: none
Other comments: pumped dry at about 1 gal

Groundwater Sampling Record

Monitoring Well No. MW 105 (Continued)

5 [ ] SAMPLE EXTRACTION METHOD:

[ ] Bailer made of:_____
[X] Pump, type: Same as on other side
[ ] Other, describe:_____

Sample obtained is [X] GRAB; [ ] COMPOSITE SAMPLE

6 [ ] ON-SITE MEASUREMENTS:

Time	0811	0816	0821	0825			Measured with
Temp (°C)	19.3	19.1	19.1	18.9			orion 840
pH	6.29	5.31	5.31	5.31			orion 290A
Cond (µS/cm)	77.2	77.3	77.2	77.1			orion 140
DO (mg/L)	0.4	0.3	0.2	0.2			orion 840
Redox (mV)	~~[illegible]~~	~~[illegible]~~	96.7	79.0			orion 250A
gallons purged	1.5	1.5	1.5	1.5			graduated bucket

7 [ ] SAMPLE CONTAINERS (material, number, size):_____

8 [ ] ON-SITE SAMPLE TREATMENT:

[ ] Filtration: Method_____ Containers:_____
Method_____ Containers:_____
Method_____ Containers:_____

[ ] Preservatives added:

Method_____ Containers:_____
Method_____ Containers:_____
Method_____ Containers:_____
Method_____ Containers:_____

9 [ ] CONTAINER HANDLING:

[ ] Container Sides Labeled
[ ] Container Lids Taped
[ ] Containers Placed in Ice Chest

10 [ ] OTHER COMMENTS: water degassing at high rate - had to pump very slow to prevent pumping well dry.

GROUNDWATER SAMPLING RECORD

Sampling Location Shaw AFB
Sampling Dates 5/12/97 - 5/22/97

GROUND WATER SAMPLING RECORD - MONITORING WELL MW-106
(Identification)

REASON FOR SAMPLING: [X] Regular Sampling; [ ] Special Sampling;
DATE AND TIME OF SAMPLING: 5/14/97 at 5:00 a.m./(p.m.)
SAMPLE COLLECTED BY: TH/CM/CH of Parsons ES
WEATHER: sunny 80°F
DATUM FOR WATER DEPTH MEASUREMENT (Describe): TOC 2" ø stickup

MONITORING WELL CONDITION:
[X] LOCKED: [ ] UNLOCKED
WELL NUMBER (IS - IS NOT) APPARENT
STEEL CASING CONDITION IS: Good
INNER PVC CASING CONDITION IS: Good
WATER DEPTH MEASUREMENT DATUM (IS - IS NOT) APPARENT
[ ] DEFICIENCIES CORRECTED BY SAMPLE COLLECTOR
[ ] MONITORING WELL REQUIRED REPAIR (describe):

Check-off

1 [✓] EQUIPMENT CLEANED BEFORE USE WITH isopropyl, distilled water
Items Cleaned (List): probes

2 [✓] PRODUCT DEPTH NA FT. BELOW DATUM
Measured with: —

WATER DEPTH 17.72 FT. BELOW DATUM
Measured with: Solinst Water level meter

3 [✓] WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Appearance: slightly silty red-brown
Odor: none
Other Comments: —

4 [✓] WELL EVACUATION:
Method: ~~2 stage Pump~~ one stage Positive displacement Pump
Volume Removed: 5 gallons
Observations: Water (slightly - very) cloudy
Water level (rose - fell - no change)
Water odors: sulfur dioxide
Other comments: —

Groundwater Sampling Record

Monitoring Well No. MW106 (Continued)

5 [X] SAMPLE EXTRACTION METHOD:

[ ] Bailer made of: _____

[X] Pump, type: Peristaltic

[ ] Other, describe: _____

Sample obtained is [X] GRAB; [ ] COMPOSITE SAMPLE

6 [✓] ON-SITE MEASUREMENTS:

Time	4:39	4:42	4:45	4:49	4:53		Measured with
Temp (°C)	19.1	18.4	18.3	18.2	18.1		Orion 840
pH	5.85	5.76	5.75	5.77	5.77		Orion 290A
Cond (µS/cm)	4170	3630	3360	31.9	30.9		Orion 140
DO (mg/L)	1.0	0.7	0.5	0.3	0.3		Orion 840
Redox (mV)	-90	-99.5	-100.8	-101.1	-100.2		Orion 290A
gallons purged	5.25	5.5	5.75	6.0	6.5		5 gallon bucket

7 [✓] SAMPLE CONTAINERS (material, number, size): 4 40ml VOA vials
2 50ml serum bottles (glass)
2 125ml plastic Nalgene bottles
2 250ml plastic Nalgene bottles (on-site analysis)

8 [ ] ON-SITE SAMPLE TREATMENT:

[ ] Filtration: Method _____ Containers: _____
Method _____ Containers: _____
Method _____ Containers: _____

[ ] Preservatives added:

Method _____ Containers: _____
Method _____ Containers: _____
Method _____ Containers: _____
Method _____ Containers: _____

9 [ ] CONTAINER HANDLING:

[ ] Container Sides Labeled
[ ] Container Lids Taped
[ ] Containers Placed in Ice Chest

10 [✓] OTHER COMMENTS: EPA collected & handled samples

GROUNDWATER SAMPLING RECORD

Sampling Location Shaw AFB
Sampling Dates 5/12/97 - 5/22/97

GROUND WATER SAMPLING RECORD - MONITORING WELL MW-107
(Identification)

REASON FOR SAMPLING: [X] Regular Sampling; [ ] Special Sampling;
DATE AND TIME OF SAMPLING: 5/14/97 at 3:15 a.m./(p.m.)
SAMPLE COLLECTED BY: TH/CM/CH of Parsons ES
WEATHER: sunny & 80°F
DATUM FOR WATER DEPTH MEASUREMENT (Describe): TOC 2" Ø PVC stickup

MONITORING WELL CONDITION:
[X] LOCKED: [ ] UNLOCKED
WELL NUMBER (IS - IS NOT) APPARENT
STEEL CASING CONDITION IS: Good
INNER PVC CASING CONDITION IS: Good
WATER DEPTH MEASUREMENT DATUM (IS - IS NOT) APPARENT
[ ] DEFICIENCIES CORRECTED BY SAMPLE COLLECTOR
[ ] MONITORING WELL REQUIRED REPAIR (describe):

Check-off
1 [✓] EQUIPMENT CLEANED BEFORE USE WITH isopropyl, distilled water
Items Cleaned (List): probes

2 [✓] PRODUCT DEPTH NA FT. BELOW DATUM
Measured with: Solinst Interface Probe

WATER DEPTH 11.33 FT. BELOW DATUM
Measured with: Solinst Interface Probe
TD = 19.90' Purge Vol 4.2 gallons

3 [✓] WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Appearance: silty red-brown
Odor: none
Other Comments: —

4 [✓] WELL EVACUATION:
Method: Two Stage Pump
Volume Removed: 15 gallons
Observations: Water (slightly - very) cloudy
Water level (rose - fell) - no change)
Water odors: none
Other comments: —

Groundwater Sampling Record

Monitoring Well No. MW-107 (Continued)

5 [✓] SAMPLE EXTRACTION METHOD:

[ ] Bailer made of:_____

[X] Pump, type: 2-stage

[ ] Other, describe:_____

Sample obtained is [X] GRAB; [ ] COMPOSITE SAMPLE

6 [✓] ON-SITE MEASUREMENTS:

Time	3:00 p	3:05 p	3:10 p				Measured with
Temp (°C)	18.3	17.5	17.4				YSI 3500
pH	5.56	5.47	5.38				
Cond (~~µS/cm~~) mS/cm	0.028	0.027	0.026				
DO (mg/L)	2.7	2.7	2.7				YSI 516
Redox (mV)	372	388	99				↓
gallons purged							

7 [✓] SAMPLE CONTAINERS (material, number, size): 4 40ml VOA vials
2 50 ml glass serum bottles
2 125 ml plastic Nalgene bottles
2 250 ml plastic Nalgene bottles

8 [ ] ON-SITE SAMPLE TREATMENT:

[ ] Filtration: Method_____ Containers:_____
Method_____ Containers:_____
Method_____ Containers:_____

[ ] Preservatives added:

Method_____ Containers:_____
Method_____ Containers:_____
Method_____ Containers:_____
Method_____ Containers:_____

9 [ ] CONTAINER HANDLING:

[ ] Container Sides Labeled
[ ] Container Lids Taped
[ ] Containers Placed in Ice Chest

10 [✓] OTHER COMMENTS: EPA collected & handled samples

GROUNDWATER SAMPLING RECORD

Sampling Location Shaw AFB
Sampling Dates 5/12/97 - 5/22/97

GROUND WATER SAMPLING RECORD - MONITORING WELL MW 111
(Identification)

REASON FOR SAMPLING: [X] Regular Sampling; [ ] Special Sampling;
DATE AND TIME OF SAMPLING: 5/15/97 at 1017 a.m./p.m.
SAMPLE COLLECTED BY: ~~TMC/SH of Parsons ES~~ DK & FB of EPA
WEATHER: hazy, light wind, nice temp.
DATUM FOR WATER DEPTH MEASUREMENT (Describe): casing marked

MONITORING WELL CONDITION:
[X] LOCKED: [ ] UNLOCKED
WELL NUMBER (IS - IS NOT) APPARENT
STEEL CASING CONDITION IS: good
INNER PVC CASING CONDITION IS: good
WATER DEPTH MEASUREMENT DATUM (IS - IS NOT) APPARENT
[ ] DEFICIENCIES CORRECTED BY SAMPLE COLLECTOR
[ ] MONITORING WELL REQUIRED REPAIR (describe):

Check-off

1 [ ] EQUIPMENT CLEANED BEFORE USE WITH new tubing
Items Cleaned (List):

2 [ ] PRODUCT DEPTH _____ FT. BELOW DATUM
Measured with:

WATER DEPTH 21.02 FT. BELOW DATUM
Measured with: water level meter

3 [ ] WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Appearance:
Odor:
Other Comments:

4 [ ] WELL EVACUATION:
Method: peristaltic pump
Volume Removed: 5.0 gal
Observations: Water (slightly - (very) cloudy
Water level (rose - fell - no change)
Water odors: none noticable
Other comments:

Groundwater Sampling Record

Monitoring Well No. MW 111 (Continued)

5 [ ] SAMPLE EXTRACTION METHOD:

[ ] Bailer made of:_____
[X] Pump, type: Cole Parmer peristaltic pump
[ ] Other, describe:_____

Sample obtained is [X] GRAB; [ ] COMPOSITE SAMPLE

6 [ ] ON-SITE MEASUREMENTS:

Time	1039	1044	1049	1053			Measured with
Temp (°C)	18.9	18.9	19.1	19.0			
pH	4.796	4.779	4.799	4.806			
Cond (µS/cm)	19.4	19.2	19.1	19.0			
DO (mg/L)	8.6	8.3	8.0	8.0			
Redox (mV)	208.3	213.2	219.1	221.6			
gallons purged	1	1.25	2.0	2.5			

7 [ ] SAMPLE CONTAINERS (material, number, size):_____

8 [ ] ON-SITE SAMPLE TREATMENT:

[ ] Filtration: Method_____ Containers:_____
Method_____ Containers:_____
Method_____ Containers:_____

[ ] Preservatives added:

Method_____ Containers:_____
Method_____ Containers:_____
Method_____ Containers:_____
Method_____ Containers:_____

9 [ ] CONTAINER HANDLING:

[ ] Container Sides Labeled
[ ] Container Lids Taped
[ ] Containers Placed in Ice Chest

10 [ ] OTHER COMMENTS:_____

GROUNDWATER SAMPLING RECORD

Sampling Location Shaw AFB
Sampling Dates 5/12/97 - 5/22/97

GROUND WATER SAMPLING RECORD - MONITORING WELL MW 112
(Identification)

REASON FOR SAMPLING: [X] Regular Sampling; [ ] Special Sampling;
DATE AND TIME OF SAMPLING: 5/16/97 at 0746 a.m./p.m.
SAMPLE COLLECTED BY: ~~TH/CM/SH~~ of ~~Parsons ES~~
WEATHER: Clear & Cool with light wind
DATUM FOR WATER DEPTH MEASUREMENT (Describe): black marker on PVC casing

MONITORING WELL CONDITION:
[ ] LOCKED: [ ] UNLOCKED
WELL NUMBER (IS - IS NOT) APPARENT
STEEL CASING CONDITION IS: totally Corroded
INNER PVC CASING CONDITION IS: broken
WATER DEPTH MEASUREMENT DATUM (IS - IS NOT) APPARENT
[ ] DEFICIENCIES CORRECTED BY SAMPLE COLLECTOR
[ ] MONITORING WELL REQUIRED REPAIR (describe):

Check-off

1 [ ] EQUIPMENT CLEANED BEFORE USE WITH new tubing used
Items Cleaned (List):

2 [ ] PRODUCT DEPTH _____ FT. BELOW DATUM
Measured with:

WATER DEPTH 15.12' FT. BELOW DATUM
Measured with: water probe

3 [ ] WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Appearance:
Odor: Strong odor
Other Comments:

4 [ ] WELL EVACUATION:
Method: tubing pump
Volume Removed:
Observations: Water (slightly - very) cloudy not
Water level (rose - fell - no change)
Water odors: strong organic
Other comments:

Groundwater Sampling Record

Monitoring Well No. MW 112 (Continued)

5 [ ] SAMPLE EXTRACTION METHOD:

[ ] Bailer made of:_____
[X] Pump, type: Tubing pump
[ ] Other, describe:_____

Sample obtained is [X] GRAB; [ ] COMPOSITE SAMPLE

6 [ ] ON-SITE MEASUREMENTS:

Time	0808	0811	0817	0822	0827		Measured with
Temp (°C)	17.9	18.0	18.2	18.2	18.3		
pH	5.622	5.558	5.474	5.414	5.403		
Cond (µS/cm)	108	108	108	108	108		
DO (mg/L)	0.1	0.0	0.0	0.0	0.0		
Redox (mV)	-153.9	-161.4	-178.2	-183.6	-184.3		
gallons purged	2.0	2.2	2.5	2.75	3.25		

7 [ ] SAMPLE CONTAINERS (material, number, size):_____

8 [ ] ON-SITE SAMPLE TREATMENT:

[ ] Filtration: Method_____ Containers:_____
Method_____ Containers:_____
Method_____ Containers:_____

[ ] Preservatives added:

Method_____ Containers:_____
Method_____ Containers:_____
Method_____ Containers:_____
Method_____ Containers:_____

9 [ ] CONTAINER HANDLING:

[ ] Container Sides Labeled
[ ] Container Lids Taped
[ ] Containers Placed in Ice Chest

10 [ ] OTHER COMMENTS:_____

GROUNDWATER SAMPLING RECORD

Sampling Location Shaw AFB
Sampling Dates 5/12/97 - 5/22/97

GROUND WATER SAMPLING RECORD - MONITORING WELL MW 112 A
(Identification)

REASON FOR SAMPLING: [X] Regular Sampling; [ ] Special Sampling;
DATE AND TIME OF SAMPLING: 5/16/97 at 0746 a.m./p.m.
SAMPLE COLLECTED BY: ~~[illegible]~~ of ~~[illegible]~~
WEATHER: Clear + Cool with light breeze
DATUM FOR WATER DEPTH MEASUREMENT (Describe): black mark on casing

MONITORING WELL CONDITION:
[ ] LOCKED: [ ] UNLOCKED
WELL NUMBER (IS - IS NOT) APPARENT
STEEL CASING CONDITION IS: good
INNER PVC CASING CONDITION IS: fair
WATER DEPTH MEASUREMENT DATUM (IS - IS NOT) APPARENT
[ ] DEFICIENCIES CORRECTED BY SAMPLE COLLECTOR
[ ] MONITORING WELL REQUIRED REPAIR (describe):

Check-off

1 [ ] EQUIPMENT CLEANED BEFORE USE WITH [illegible]
Items Cleaned (List):

2 [ ] PRODUCT DEPTH _____ FT. BELOW DATUM
Measured with:

WATER DEPTH 19.62 FT. BELOW DATUM
Measured with: water probe

3 [ ] WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Appearance:
Odor:
Other Comments:

4 [ ] WELL EVACUATION:
Method: 12 volt pump
Volume Removed:
Observations: Water (slightly - very) cloudy none
Water level (rose - fell - no change)
Water odors: none
Other comments:

Groundwater Sampling Record

Monitoring Well No. MW 112 R (Continued)

5 [ ] SAMPLE EXTRACTION METHOD:

[ ] Bailer made of:_____
[X] Pump, type: tubing pump
[ ] Other, describe:_____

Sample obtained is [X] GRAB; [ ] COMPOSITE SAMPLE

6 [ ] ON-SITE MEASUREMENTS:

Time	0904	0917	0945				Measured with
Temp (°C)	19.2	19.4	18.8				
pH	6.094	5.425	5.38				
Cond (µS/cm)	21	19	19				
DO (mg/L)	6.8	6.1	5.6				
Redox (mV)	105.3	157.7	200.4				
gallons purged	51	52	54				

7 [ ] SAMPLE CONTAINERS (material, number, size):_____

8 [ ] ON-SITE SAMPLE TREATMENT:

[ ] Filtration: Method_____ Containers:_____
Method_____ Containers:_____
Method_____ Containers:_____

[ ] Preservatives added:

Method_____ Containers:_____
Method_____ Containers:_____
Method_____ Containers:_____
Method_____ Containers:_____

9 [ ] CONTAINER HANDLING:

[ ] Container Sides Labeled
[ ] Container Lids Taped
[ ] Containers Placed in Ice Chest

10 [ ] OTHER COMMENTS:_____

GROUNDWATER SAMPLING RECORD

Sampling Location Shaw AFB
Sampling Dates 5/12/97 - 5/22/97

GROUND WATER SAMPLING RECORD - MONITORING WELL MW-113 (GW)
(Identification)

REASON FOR SAMPLING: [X] Regular Sampling; [ ] Special Sampling;
DATE AND TIME OF SAMPLING: 5/15/97 at 9:00 a.m./p.m.
SAMPLE COLLECTED BY: TH/CM/CH of Parsons ES
WEATHER: Sunny & 85°F
DATUM FOR WATER DEPTH MEASUREMENT (Describe): TOC 2" ↑ stickup

MONITORING WELL CONDITION:
[X] LOCKED: [ ] UNLOCKED
WELL NUMBER (IS - IS NOT) APPARENT
STEEL CASING CONDITION IS: Good
INNER PVC CASING CONDITION IS: Good
WATER DEPTH MEASUREMENT DATUM (IS - IS NOT) APPARENT
[ ] DEFICIENCIES CORRECTED BY SAMPLE COLLECTOR
[ ] MONITORING WELL REQUIRED REPAIR (describe):

Check-off
1 [X] EQUIPMENT CLEANED BEFORE USE WITH isopropyl, distilled water
Items Cleaned (List): probes

2 [X] PRODUCT DEPTH NA FT. BELOW DATUM
Measured with: —

WATER DEPTH 6.5 FT. BELOW DATUM
Measured with:
TD 25' Purge ~10 gallons

3 [X] WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Appearance:
Odor:
Other Comments:

4 [X] WELL EVACUATION:
Method: 2 stage pump
Volume Removed:
Observations: Water (slightly - very) cloudy
Water level (rose - fell - no change)
Water odors:
Other comments:

Groundwater Sampling Record

Monitoring Well No. MW-113 (Continued)

5 [Y] SAMPLE EXTRACTION METHOD:

[ ] Bailer made of:_____
[Y] Pump, type: 2 stage
[ ] Other, describe:_____

Sample obtained is [X] GRAB; [ ] COMPOSITE SAMPLE

6 [ ] ON-SITE MEASUREMENTS:

Time	8:40a	8:45a	8:50a				Measured with
Temp (°C)	16.0	16.4	16.4				
pH	5.30	4.42	4.46				
mS/cm → Cond	0.020	0.017	0.017				
DO (mg/L)	4.5	4.4	3.8				
Redox (mV)	77	154	165				
gallons purged	2	5	8				

7 [Y] SAMPLE CONTAINERS (material, number, size): 4 40 ml VOA vials
2 50 ml glass serum bottles
2 125 ml plastic Nalgene bottles
2 250 ml plastic Nalgene bottles

8 [ ] ON-SITE SAMPLE TREATMENT:

[ ] Filtration: Method_____ Containers:_____
Method_____ Containers:_____
Method_____ Containers:_____

[ ] Preservatives added:

Method_____ Containers:_____
Method_____ Containers:_____
Method_____ Containers:_____
Method_____ Containers:_____

9 [ ] CONTAINER HANDLING:

[ ] Container Sides Labeled
[ ] Container Lids Taped
[ ] Containers Placed in Ice Chest

10 [Y] OTHER COMMENTS: EPA handled samples

GROUNDWATER SAMPLING RECORD

Sampling Location Shaw AFB
Sampling Dates 5/12/97 - 5/22/97

GROUND WATER SAMPLING RECORD - MONITORING WELL MW-114
(Identification)

REASON FOR SAMPLING: [X] Regular Sampling; [ ] Special Sampling;
DATE AND TIME OF SAMPLING: 5/15/97 at 330 a.m./(p.m.)
SAMPLE COLLECTED BY: TH/CM/CH of Parsons ES
WEATHER: sunny & hot
DATUM FOR WATER DEPTH MEASUREMENT (Describe): TOC 2" stickup

MONITORING WELL CONDITION:
[X] LOCKED: [ ] UNLOCKED
WELL NUMBER (IS - IS NOT) APPARENT
STEEL CASING CONDITION IS: Good
INNER PVC CASING CONDITION IS: Good
WATER DEPTH MEASUREMENT DATUM (IS - IS NOT) APPARENT
[ ] DEFICIENCIES CORRECTED BY SAMPLE COLLECTOR
[ ] MONITORING WELL REQUIRED REPAIR (describe):

Check-off
1 [✓] EQUIPMENT CLEANED BEFORE USE WITH isopropyl, distilled water
Items Cleaned (List): probes

2 [✓] PRODUCT DEPTH NA FT. BELOW DATUM
Measured with:

WATER DEPTH 7.27 FT. BELOW DATUM
Measured with: Solinst

3 [✓] WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Appearance: Clear
Odor: ~~none~~ rotten eggs
Other Comments: —

4 [✓] WELL EVACUATION:
Method: 2 stage pump
Volume Removed: 10 gallons
Observations: Water (slightly - very) cloudy
Water level (rose - (fell) - no change)
Water odors: rotten eggs
Other comments: —

Groundwater Sampling Record

Monitoring Well No. 114 (Continued)

5 [✓] SAMPLE EXTRACTION METHOD:

[ ] Bailer made of:_____

[X] Pump, type: 2 stage

[ ] Other, describe:_____

Sample obtained is [X] GRAB; [ ] COMPOSITE SAMPLE

6 [✓] ON-SITE MEASUREMENTS:

Time	3:00 p	3:10	3:15	3:20			Measured with
Temp (°C)	19.7	17.3	16.7	16.9			YSI 3500
pH	4.68	4.45	4.9	4.9			
Cond (µS/cm)	0.021	0.019	0.001	0.009			
DO (mg/L)	0.5	0.5	0.4	0.4			(YSI 51B)
Redox (mV)	84	73	74	71			
gallons purged	4	7	8	12			5 gallon bucket

7 [✓] SAMPLE CONTAINERS (material, number, size): 4 40ml VOA vials
2 125ml plastic nalgene bottles
2 50ml glass serum bottles
2 250ml plastic Nalgene bottles (for on-site analysis)

8 [ ] ON-SITE SAMPLE TREATMENT:

[ ] Filtration: Method_____ Containers:_____
Method_____ Containers:_____
Method_____ Containers:_____

[ ] Preservatives added:

Method_____ Containers:_____
Method_____ Containers:_____
Method_____ Containers:_____
Method_____ Containers:_____

9 [ ] CONTAINER HANDLING:

[ ] Container Sides Labeled
[ ] Container Lids Taped
[ ] Containers Placed in Ice Chest

10 [✓] OTHER COMMENTS: EPA handled samples

GROUNDWATER SAMPLING RECORD

Sampling Location Shaw AFB
Sampling Dates 5/12/97 - 5/22/97

GROUND WATER SAMPLING RECORD - MONITORING WELL MW 115
(Identification)

REASON FOR SAMPLING: [X] Regular Sampling; [ ] Special Sampling;
DATE AND TIME OF SAMPLING: 5/15/97 at 1215 a.m./p.m.
SAMPLE COLLECTED BY: ~~TMC/MCH of Parsons ES~~ DK & FB of EPA
WEATHER: Sunny 115 A
DATUM FOR WATER DEPTH MEASUREMENT (Describe): marked on broken PVC casing

MONITORING WELL CONDITION:
[ ] LOCKED: [ ] UNLOCKED
WELL NUMBER (IS - IS NOT) APPARENT
STEEL CASING CONDITION IS: good
INNER PVC CASING CONDITION IS: fair
WATER DEPTH MEASUREMENT DATUM (IS - IS NOT) APPARENT
[ ] DEFICIENCIES CORRECTED BY SAMPLE COLLECTOR
[ ] MONITORING WELL REQUIRED REPAIR (describe):

Check-off

1 [ ] EQUIPMENT CLEANED BEFORE USE WITH
Items Cleaned (List):

2 [ ] PRODUCT DEPTH FT. BELOW DATUM
Measured with:

WATER DEPTH 4.51' FT. BELOW DATUM
Measured with:

3 [ ] WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Appearance: clear
Odor: strong organic fuel odor
Other Comments:

4 [ ] WELL EVACUATION:
Method: Tubing pump
Volume Removed:
Observations: Water (slightly - very) cloudy
Water level (rose - fell - no change)
Water odors:
Other comments:

Groundwater Sampling Record

Monitoring Well No. MW115 (Continued)

5 [ ] SAMPLE EXTRACTION METHOD:

[ ] Bailer made of:_____
[X] Pump, type: Tubing pump
[ ] Other, describe:_____

Sample obtained is [X] GRAB; [ ] COMPOSITE SAMPLE

6 [ ] ON-SITE MEASUREMENTS:

Time	1246	1250	1254	1258			Measured with
Temp (°C)	~~17.0~~ 17.4	17.4	17.3	17.3			
pH	6.099	6.023	5.999	6.003			
Cond (µS/cm)	2100	2109	211	211			
DO (mg/L)	0.0	0.0	0.0	0.0			
Redox (mV)	-190.0	-197.9	-202.5	-201.3			
gallons purged	3.0	3.5	4.0	4.25			

7 [ ] SAMPLE CONTAINERS (material, number, size):_____

8 [ ] ON-SITE SAMPLE TREATMENT:

[ ] Filtration: Method_____ Containers:_____
Method_____ Containers:_____
Method_____ Containers:_____

[ ] Preservatives added:

Method_____ Containers:_____
Method_____ Containers:_____
Method_____ Containers:_____
Method_____ Containers:_____

9 [ ] CONTAINER HANDLING:

[ ] Container Sides Labeled
[ ] Container Lids Taped
[ ] Containers Placed in Ice Chest

10 [ ] OTHER COMMENTS:_____

GROUNDWATER SAMPLING RECORD

Sampling Location Shaw AFB
Sampling Dates 5/12/97 - 5/22/97

GROUND WATER SAMPLING RECORD - MONITORING WELL MW 115A
(Identification)

REASON FOR SAMPLING: [X] Regular Sampling; [ ] Special Sampling;
DATE AND TIME OF SAMPLING: 5/15/97 at 1215 a.m./p.m.
SAMPLE COLLECTED BY: ~~TBL/CM/CH of Parsons ES~~ DK & FB of EPA
WEATHER: partly Cloudy & warm
DATUM FOR WATER DEPTH MEASUREMENT (Describe): marked on PVC casing

MONITORING WELL CONDITION:
[ ] LOCKED: [ ] UNLOCKED
WELL NUMBER (IS - IS NOT) APPARENT
STEEL CASING CONDITION IS:
INNER PVC CASING CONDITION IS:
WATER DEPTH MEASUREMENT DATUM (IS - IS NOT) APPARENT
[ ] DEFICIENCIES CORRECTED BY SAMPLE COLLECTOR
[ ] MONITORING WELL REQUIRED REPAIR (describe):

Check-off

1 [ ] EQUIPMENT CLEANED BEFORE USE WITH
Items Cleaned (List):

2 [ ] PRODUCT DEPTH FT. BELOW DATUM
Measured with:

WATER DEPTH 7.06' FT. BELOW DATUM
Measured with:

3 [ ] WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Appearance: Clean
Odor: none
Other Comments:

4 [ ] WELL EVACUATION:
Method: 12 Volt #40 pump
Volume Removed:
Observations: Water (slightly - very) cloudy
Water level (rose - fell - no change)
Water odors:
Other comments:

Groundwater Sampling Record

Monitoring Well No. _____ (Continued)

5 [ ] SAMPLE EXTRACTION METHOD:

[ ] Bailer made of:_____
[X] Pump, type: tubing pump
[ ] Other, describe:_____

Sample obtained is [X] GRAB; [ ] COMPOSITE SAMPLE

6 [ ] ON-SITE MEASUREMENTS:

Time	1314	1319	1325				Measured with
Temp (°C)	19.1	19.1	19.1				
pH	4.821	4.79	4.80				
Cond (µS/cm)	24	24	24				
DO (mg/L)	7.4	7.4	7.4				
Redox (mV)	155.4	184.7	196				
gallons purged							

7 [ ] SAMPLE CONTAINERS (material, number, size):_____

8 [ ] ON-SITE SAMPLE TREATMENT:

[ ] Filtration: Method_____ Containers:_____
Method_____ Containers:_____
Method_____ Containers:_____

[ ] Preservatives added:

Method_____ Containers:_____
Method_____ Containers:_____
Method_____ Containers:_____
Method_____ Containers:_____

9 [ ] CONTAINER HANDLING:

[ ] Container Sides Labeled
[ ] Container Lids Taped
[ ] Containers Placed in Ice Chest

10 [ ] OTHER COMMENTS:_____

GROUNDWATER SAMPLING RECORD

Sampling Location Shaw AFB
Sampling Dates 5/12/97 - 5/22/97

GROUND WATER SAMPLING RECORD - MONITORING WELL 116
(Identification)

REASON FOR SAMPLING: [X] Regular Sampling; [ ] Special Sampling;
DATE AND TIME OF SAMPLING: 5/14/97 at 12:00 a.m. (p.m.)
SAMPLE COLLECTED BY: TH/CM/CH of Parsons ES
WEATHER: sunny & warm
DATUM FOR WATER DEPTH MEASUREMENT (Describe): TOC 2" dia stickup

MONITORING WELL CONDITION:
[X] LOCKED: [ ] UNLOCKED
WELL NUMBER (IS / IS NOT) APPARENT
STEEL CASING CONDITION IS: good
INNER PVC CASING CONDITION IS: good
WATER DEPTH MEASUREMENT DATUM (IS / IS NOT) APPARENT
[ ] DEFICIENCIES CORRECTED BY SAMPLE COLLECTOR
[ ] MONITORING WELL REQUIRED REPAIR (describe):

Check-off

1 [✓] EQUIPMENT CLEANED BEFORE USE WITH isopropyl, di water
Items Cleaned (List): probes

2 [✓] PRODUCT DEPTH NA FT. BELOW DATUM
Measured with: —

WATER DEPTH 12.98 FT. BELOW DATUM
Measured with: —

3 [✓] WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Appearance: clear
Odor: none
Other Comments: —

4 [✓] WELL EVACUATION:
Method: pump (2 stage)
Volume Removed: 6 gallons
Observations: Water (slightly - very) cloudy
Water level (rose / fell / no change)
Water odors: none
Other comments: —

Groundwater Sampling Record

Monitoring Well No. 116 (Continued)

5 [✓] SAMPLE EXTRACTION METHOD:

[ ] Bailer made of: _____

[X] Pump, type: Peristaltic

[ ] Other, describe: _____

Sample obtained is [X] GRAB; [ ] COMPOSITE SAMPLE

6 [✓] ON-SITE MEASUREMENTS:

Time	1134a	11:40a	11:50a				Measured with
Temp (°C)	21.2	22.3	21.5				Orion 840
pH	NM	4.8	4.6				Orion 250A
Cond ~~(µS/cm)~~ mS/cm →	0.05	0.05	0.05				Orion 140
DO (mg/L)	8.5	8.2	8.4				Orion 840
Redox (mV)	225	234	242				Orion 250A
gallons purged							

7 [✓] SAMPLE CONTAINERS (material, number, size): 4 40ml VOA vials
2 50ml glass serum bottles
2 125ml plastic Nalgene bottles
2 250 ml plastic Nalgene bottles (on-site analysis)

8 [ ] ON-SITE SAMPLE TREATMENT:

[ ] Filtration: Method _____ Containers: _____
Method _____ Containers: _____
Method _____ Containers: _____

[ ] Preservatives added:

Method _____ Containers: _____
Method _____ Containers: _____
Method _____ Containers: _____
Method _____ Containers: _____

9 [ ] CONTAINER HANDLING:

[ ] Container Sides Labeled
[ ] Container Lids Taped
[ ] Containers Placed in Ice Chest

10 [✓] OTHER COMMENTS: EPA handled samples

GROUNDWATER SAMPLING RECORD

Sampling Location Shaw AFB
Sampling Dates 5/12/97 - 5/22/97

GROUND WATER SAMPLING RECORD - MONITORING WELL MW-117
(Identification)

REASON FOR SAMPLING: [X] Regular Sampling; [ ] Special Sampling;
DATE AND TIME OF SAMPLING: 5/15 at 1530 a.m./p.m.
SAMPLE COLLECTED BY: ~~[illegible]~~ of Parsons ES
WEATHER: cloudy - warm
DATUM FOR WATER DEPTH MEASUREMENT (Describe): TOC

MONITORING WELL CONDITION:
[X] LOCKED: [ ] UNLOCKED.
WELL NUMBER (IS - IS NOT) APPARENT
STEEL CASING CONDITION IS: Good - water in aluminum casing
INNER PVC CASING CONDITION IS: Good
WATER DEPTH MEASUREMENT DATUM (IS - IS NOT) APPARENT
[ ] DEFICIENCIES CORRECTED BY SAMPLE COLLECTOR
[ ] MONITORING WELL REQUIRED REPAIR (describe):

Check-off

1 [ ] EQUIPMENT CLEANED BEFORE USE WITH new tubing
Items Cleaned (List):

2 [ ] PRODUCT DEPTH FT. BELOW DATUM
Measured with:

WATER DEPTH 14.66' FT. BELOW DATUM
Measured with: water probe

3 [ ] WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Appearance: clear
Odor: none
Other Comments:

4 [ ] WELL EVACUATION:
Method: tubing pump
Volume Removed:
Observations: Water (slightly - very) cloudy
Water level (rose - fell - no change)
Water odors: none
Other comments:

Groundwater Sampling Record

Monitoring Well No. MW117 (Continued)

5 [ ] SAMPLE EXTRACTION METHOD:

[ ] Bailer made of:_____
[X] Pump, type: Tubing pump
[ ] Other, describe:_____

Sample obtained is [X] GRAB; [ ] COMPOSITE SAMPLE

6 [ ] ON-SITE MEASUREMENTS:

Time	1631	1635	1638				Measured with
Temp (°C)	19.9	19.8	19.9				
pH	4.388	4.390	4.394				
Cond (µS/cm)	62	61	62				
DO (mg/L)	9.5	9.4	9.0				
Redox (mV)	313.2	312.0	319.4				
gallons purged	6 gal	6.5	6.75				

7 [ ] SAMPLE CONTAINERS (material, number, size):_____

8 [ ] ON-SITE SAMPLE TREATMENT:

[ ] Filtration: Method_____ Containers:_____
Method_____ Containers:_____
Method_____ Containers:_____

[ ] Preservatives added:

Method_____ Containers:_____
Method_____ Containers:_____
Method_____ Containers:_____
Method_____ Containers:_____

9 [ ] CONTAINER HANDLING:

[ ] Container Sides Labeled
[ ] Container Lids Taped
[ ] Containers Placed in Ice Chest

10 [ ] OTHER COMMENTS:_____

GROUNDWATER SAMPLING RECORD

Sampling Location Shaw AFB
Sampling Dates 5/12/97 - 5/22/97

GROUND WATER SAMPLING RECORD - MONITORING WELL : MW 118
(Identification)

REASON FOR SAMPLING: [X] Regular Sampling; [ ] Special Sampling;
DATE AND TIME OF SAMPLING: 5/15/97 at 1409 a.m./p.m.
SAMPLE COLLECTED BY: ~~[illegible]~~ of ~~[illegible]~~
WEATHER: clear & hot some wind but not where we are
DATUM FOR WATER DEPTH MEASUREMENT (Describe): black marker on PVC casing

MONITORING WELL CONDITION:
[X] LOCKED: [ ] UNLOCKED
WELL NUMBER (IS - IS NOT) APPARENT
STEEL CASING CONDITION IS: Aluminum
INNER PVC CASING CONDITION IS: good
WATER DEPTH MEASUREMENT DATUM (IS - IS NOT) APPARENT
[ ] DEFICIENCIES CORRECTED BY SAMPLE COLLECTOR
[ ] MONITORING WELL REQUIRED REPAIR (describe):

Check-off

1 [ ] EQUIPMENT CLEANED BEFORE USE WITH
Items Cleaned (List):

2 [ ] PRODUCT DEPTH FT. BELOW DATUM
Measured with:

WATER DEPTH 4.14 FT. BELOW DATUM
Measured with: water probe

3 [ ] WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Appearance: Clear
Odor: none
Other Comments:

4 [ ] WELL EVACUATION:
Method: tubing pump
Volume Removed:
Observations: Water (slightly - very) cloudy not
Water level (rose - fell (no change))
Water odors: none
Other comments:

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Best Available Copy

Groundwater Sampling Record

Monitoring Well No. MW19 (Continued)

5 [ ] SAMPLE EXTRACTION METHOD:

[ ] Bailer made of: ~~S~~

[X] Pump, type: Tubing Pump

[ ] Other, describe: _____

Sample obtained is [X] GRAB; [ ] COMPOSITE SAMPLE

6 [ ] ON-SITE MEASUREMENTS:

Time	1427	1433	1438	1442	1445		Measured with
Temp (°C)	17.8	17.6	17.5	17.5	17.5		
pH	6.512	6.084	5.916	5.883	5.840		
Cond (µS/cm)	76	78	79	78	78		
DO (mg/L)	2.4	2.5	2.6	2.6	2.5		
Redox (mV)	162.2	169.9	171.8	173.6	173.6		
gallons purged	1 gal	1.5	2.0	2.25	2.5	3.0	

7 [ ] SAMPLE CONTAINERS (material, number, size): _____

8 [ ] ON-SITE SAMPLE TREATMENT:

[ ] Filtration: Method _____ Containers: _____
Method _____ Containers: _____
Method _____ Containers: _____

[ ] Preservatives added:

Method _____ Containers: _____
Method _____ Containers: _____
Method _____ Containers: _____
Method _____ Containers: _____

9 [ ] CONTAINER HANDLING:

[ ] Container Sides Labeled
[ ] Container Lids Taped
[ ] Containers Placed in Ice Chest

10 [ ] OTHER COMMENTS: _____

GROUNDWATER SAMPLING RECORD

Sampling Location Shaw AFB
Sampling Dates 5/12/97 - 5/22/97

GROUND WATER SAMPLING RECORD - MONITORING WELL 116A
(Identification)

REASON FOR SAMPLING: [X] Regular Sampling; [ ] Special Sampling;
DATE AND TIME OF SAMPLING: 5/14/97 at 1130 (a.m./p.m.
SAMPLE COLLECTED BY: TH/CM/CH of Parsons ES
WEATHER: Sunny & warm 75°F
DATUM FOR WATER DEPTH MEASUREMENT (Describe): TOC 2" diam. stickup

MONITORING WELL CONDITION:
[X] LOCKED: [ ] UNLOCKED
WELL NUMBER (IS / IS NOT) APPARENT
STEEL CASING CONDITION IS: good
INNER PVC CASING CONDITION IS: good
WATER DEPTH MEASUREMENT DATUM (IS / IS NOT) APPARENT North
[ ] DEFICIENCIES CORRECTED BY SAMPLE COLLECTOR
[ ] MONITORING WELL REQUIRED REPAIR (describe):

Check-off

1 [✓] EQUIPMENT CLEANED BEFORE USE WITH isopropyl, distilled water
Items Cleaned (List): probes, pump, tubing

2 [✓] PRODUCT DEPTH NA FT. BELOW DATUM
Measured with:

WATER DEPTH 17.79 FT. BELOW DATUM
Measured with:

3 [✓] WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Appearance: clear
Odor: none
Other Comments:

4 [✓] WELL EVACUATION:
Method: 2 stage Pump
Volume Removed: 35 gallons
Observations: Water (slightly / very) cloudy
Water level (rose / fell / no change)
Water odors: none
Other comments:

Groundwater Sampling Record

Monitoring Well No. 116A (Continued)

5 [✓] SAMPLE EXTRACTION METHOD:

[ ] Bailer made of:_____

[X] Pump, type: Two Stage

[ ] Other, describe:_____

Sample obtained is [X] GRAB; [ ] COMPOSITE SAMPLE

6 [✓] ON-SITE MEASUREMENTS:

Time	10:46a	10:59a	11:07				Measured with
Temp (°C)	20.0	20.0	20.0				YSI 3500
pH	5.05	5.08	5.03				YSI 3500
Cond (~~µS/cm~~ mmoh/cm)	0.018	0.020	0.190				YSI 3500
DO (mg/L)	5.2	5.6	5.0				YSI 5i8
Redox (mV)	214	255	268				YSI 3500
gallons purged	15	20	25				5 gallon bucket

7 [✓] SAMPLE CONTAINERS (material, number, size): 4 40ml VOA vials
2 50ml glass serum bottles
2 125ml plastic Nalgene bottles
2 250ml plastic Nalgene bottles

8 [ ] ON-SITE SAMPLE TREATMENT:

[ ] Filtration: Method_____ Containers:_____
Method_____ Containers:_____
Method_____ Containers:_____

[ ] Preservatives added:

Method_____ Containers:_____
Method_____ Containers:_____
Method_____ Containers:_____
Method_____ Containers:_____

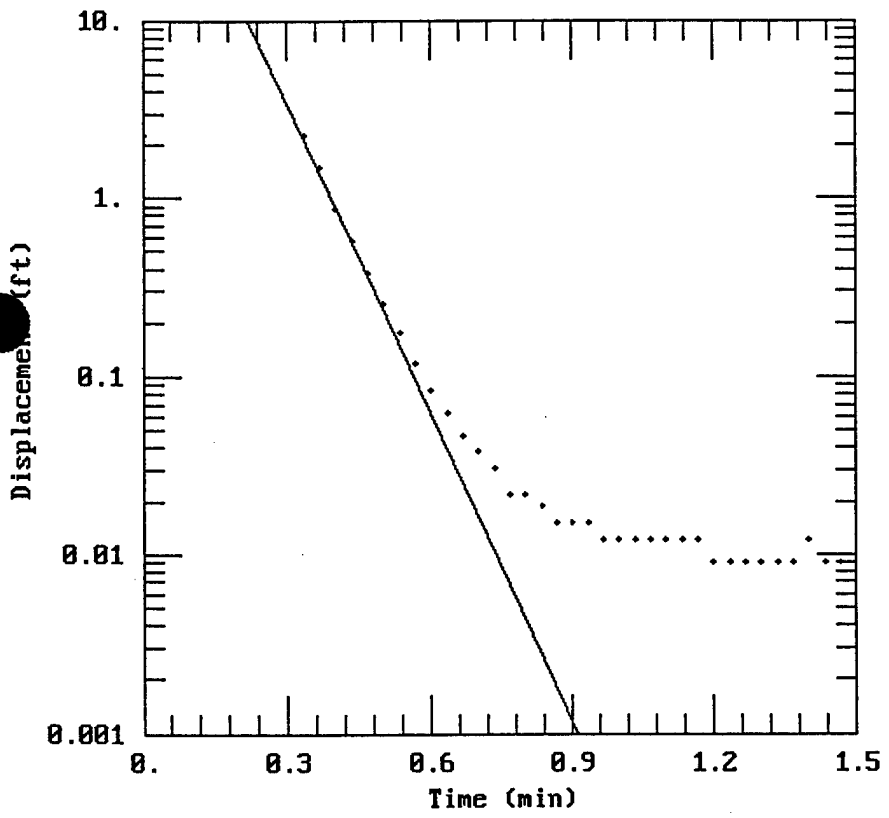
9 [ ] CONTAINER HANDLING:

[ ] Container Sides Labeled
[ ] Container Lids Taped
[ ] Containers Placed in Ice Chest

10 [✓] OTHER COMMENTS: EPA handled samples

CLIENT: AFCEE	COMPANY: Parsons E.S.
LOCATION: Shaw AFB, South Carolina	PROJECT: 722450.37020

MW-106 Falling Head Test 1



DATA SET:
MW106A.DAT
06/06/97

AQUIFER MODEL:
Unconfined

SOLUTION METHOD:
Bouwer-Rice

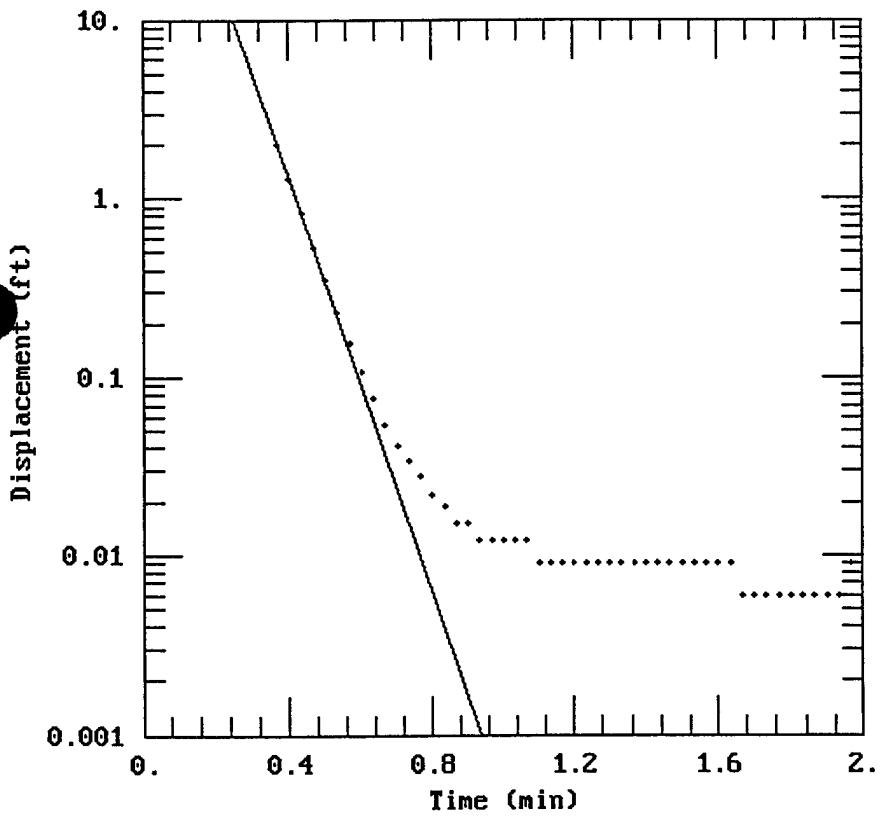
TEST DATA:
H0= 2.242 ft
r_c= 0.083 ft
r_w= 0.25 ft
L = 5. ft
b = 80. ft
H = 5. ft

PARAMETER ESTIMATES:
K = 0.05498 ft/min
y0 = 185. ft

AQTESOLV

CLIENT: AFCEE	COMPANY: Parsons E.S.
LOCATION: Shaw AFB, South Carolina	PROJECT: 722450.37020

MW-106 Rising Head Test 1



DATA SET:
MW106B.DAT
06/06/97

AQUIFER MODEL:
Unconfined

SOLUTION METHOD:
Bouwer-Rice

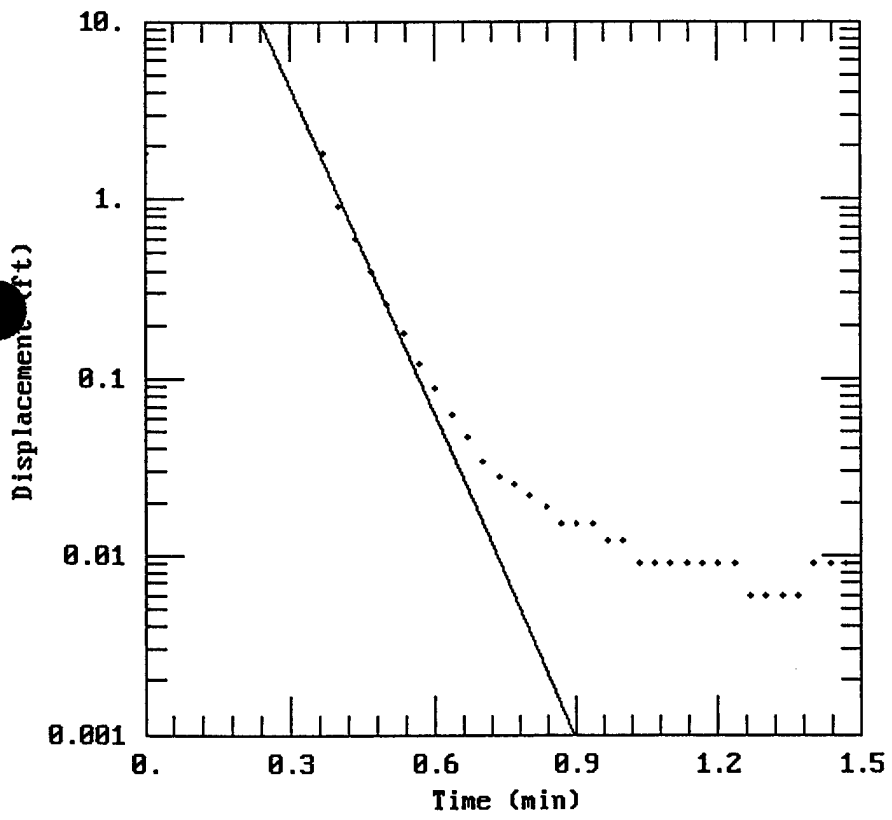
TEST DATA:
H0= 2.021 ft
r_c= 0.083 ft
r_w= 0.25 ft
L = 5. ft
b = 80. ft
H = 5. ft

PARAMETER ESTIMATES:
K = 0.05555 ft/min
y0 = 283.9 ft

AQTESOLV

CLIENT: AFCEE	COMPANY: Parsons E.S.
LOCATION: Shaw AFB, South Carolina	PROJECT: 722450.37020

MW-106 Falling Head Test 2



DATA SET:
MW106C.DAT
06/06/97

AQUIFER MODEL:
Unconfined
SOLUTION METHOD:
Bouwer-Rice

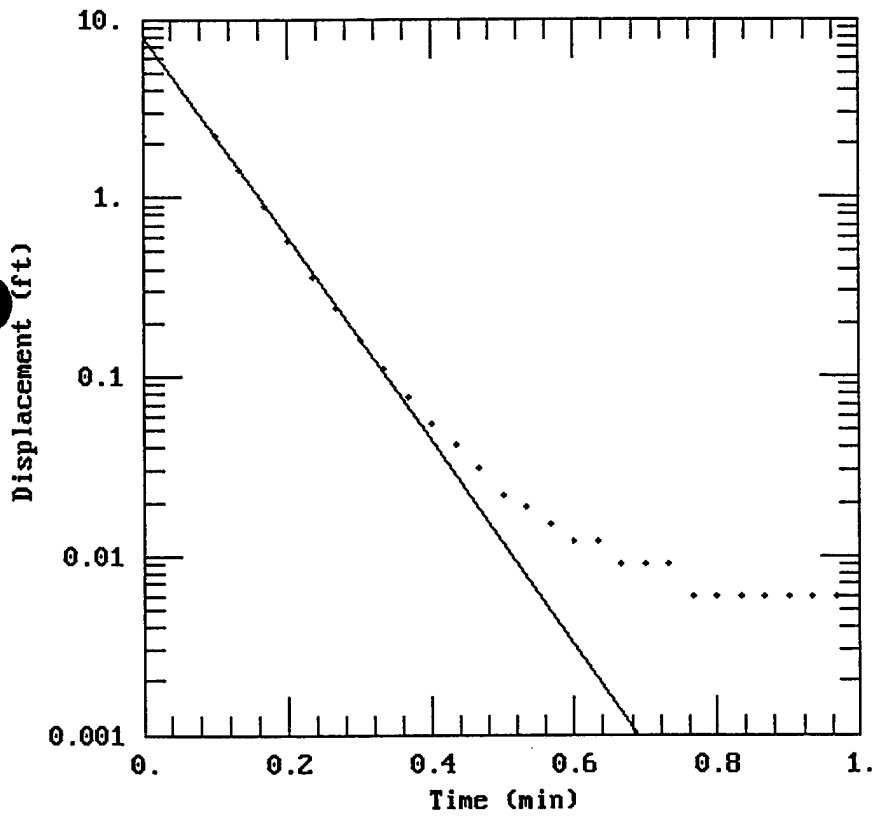
TEST DATA:
H0= 1.816 ft
r_c= 0.083 ft
r_w= 0.25 ft
L = 5. ft
b = 80. ft
H = 5. ft

PARAMETER ESTIMATES:
K = 0.05779 ft/min
y0 = 277.7 ft

AQTESOLV

CLIENT: AFCEE	COMPANY: Parsons E.S.
LOCATION: Shaw AFB, South Carolina	PROJECT: 722450.37020

MW-106 Rising Head Test 2



DATA SET:
MW106D.DAT
06/06/97

AQUIFER MODEL:
Unconfined

SOLUTION METHOD:
Bouwer-Rice

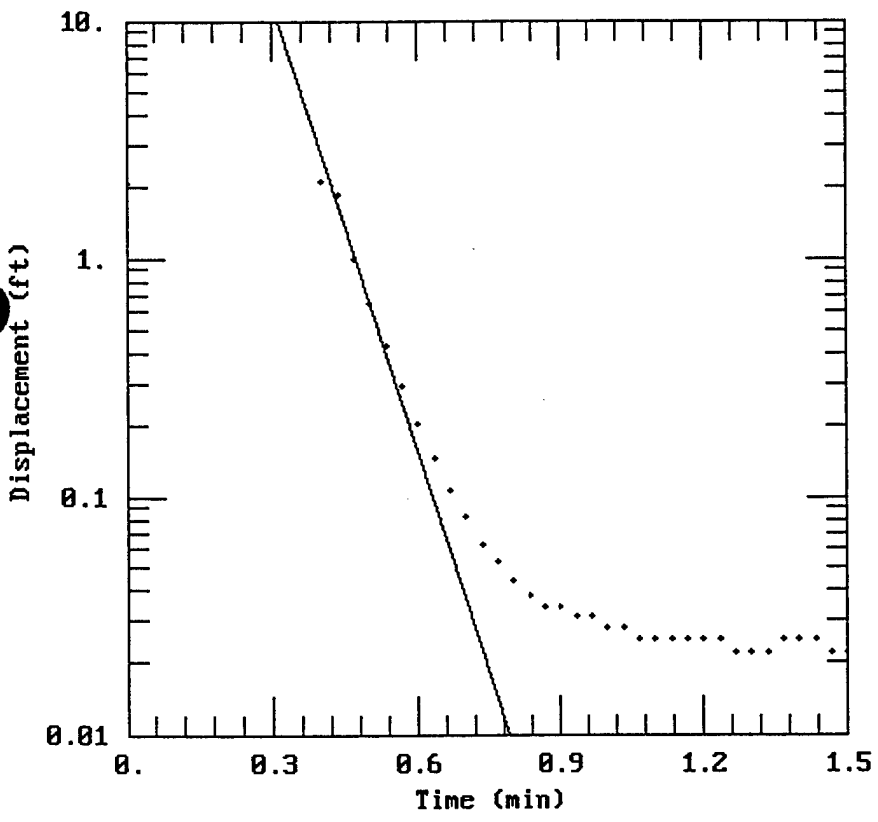
TEST DATA:
H0= 2.231 ft
r_c= 0.083 ft
r_w= 0.25 ft
L = 5. ft
b = 80. ft
H = 5. ft

PARAMETER ESTIMATES:
K = 0.05369 ft/min
y0 = 7.927 ft

AQTESOLV

CLIENT: AFCEE	COMPANY: Parsons E.S.
LOCATION: Shaw AFB, South Carolina	PROJECT: 722450.37020

MW-106 Falling Head Test 3



DATA SET:
MW106E.DAT
06/06/97

AQUIFER MODEL:
Unconfined

SOLUTION METHOD:
Bouwer-Rice

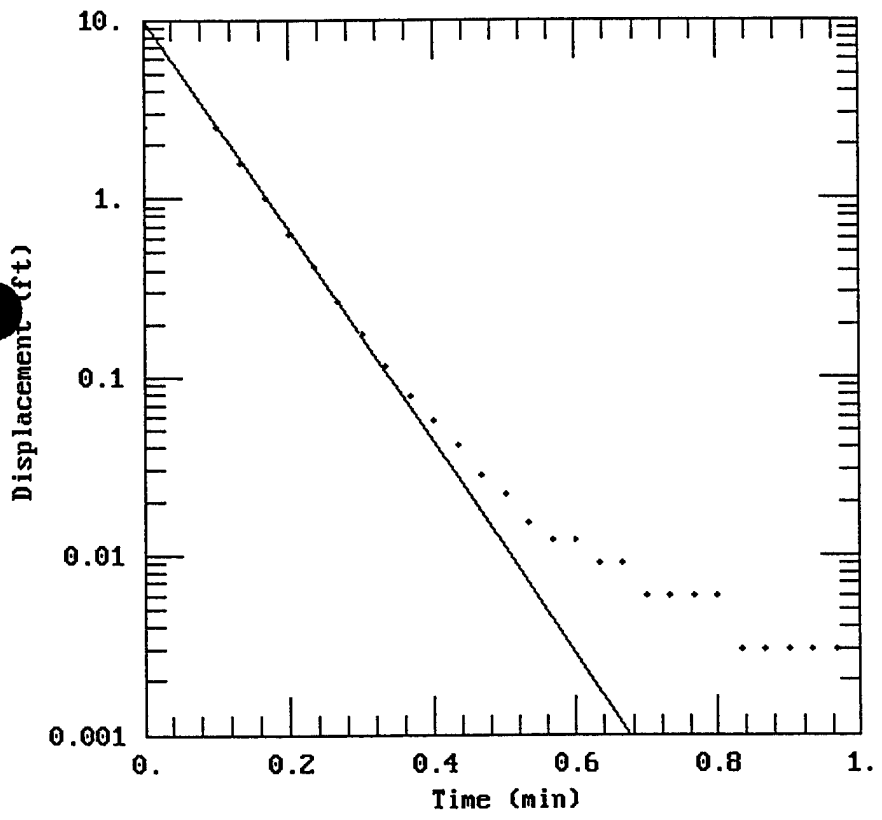
TEST DATA:
H0= 2.077 ft
r_c= 0.083 ft
r_w= 0.25 ft
L = 5. ft
b = 80. ft
H = 5. ft

PARAMETER ESTIMATES:
K = 0.0598 ft/min
y0 = 908.2 ft

AQTESOLV

CLIENT: AFCEE	COMPANY: Parsons E.S.
LOCATION: Shaw AFB, South Carolina	PROJECT: 722450.37020

MW-106 Rising Head Test 3



DATA SET:
MW106F.DAT
06/06/97

AQUIFER MODEL:
Unconfined

SOLUTION METHOD:
Bouwer-Rice

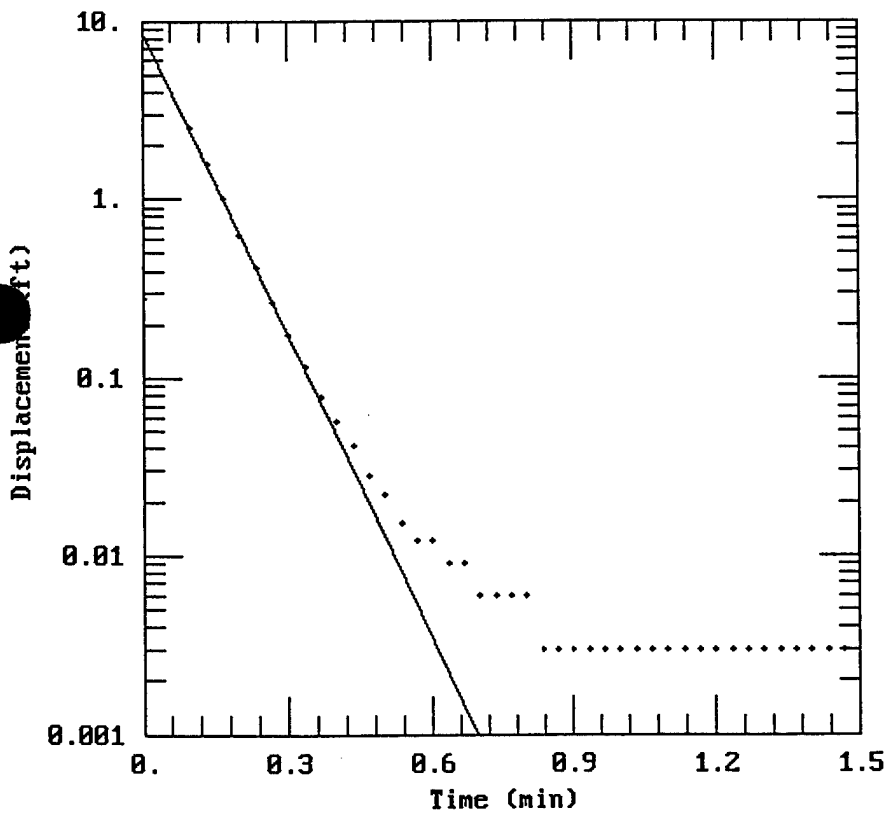
TEST DATA:
H0= 2.503 ft
r_c= 0.083 ft
r_w= 0.25 ft
L = 5. ft
b = 80. ft
H = 5. ft

PARAMETER ESTIMATES:
K = 0.05654 ft/min
y0 = 10.27 ft

AQTESOLV

CLIENT: AFCEE	COMPANY: Parsons E.S.
LOCATION: Shaw AFB, South Carolina	PROJECT: 722450.37020

MW-112 Falling Head Test 1



DATA SET:
MW112A.DAT
06/06/97

AQUIFER MODEL:
Unconfined

SOLUTION METHOD:
Bouwer-Rice

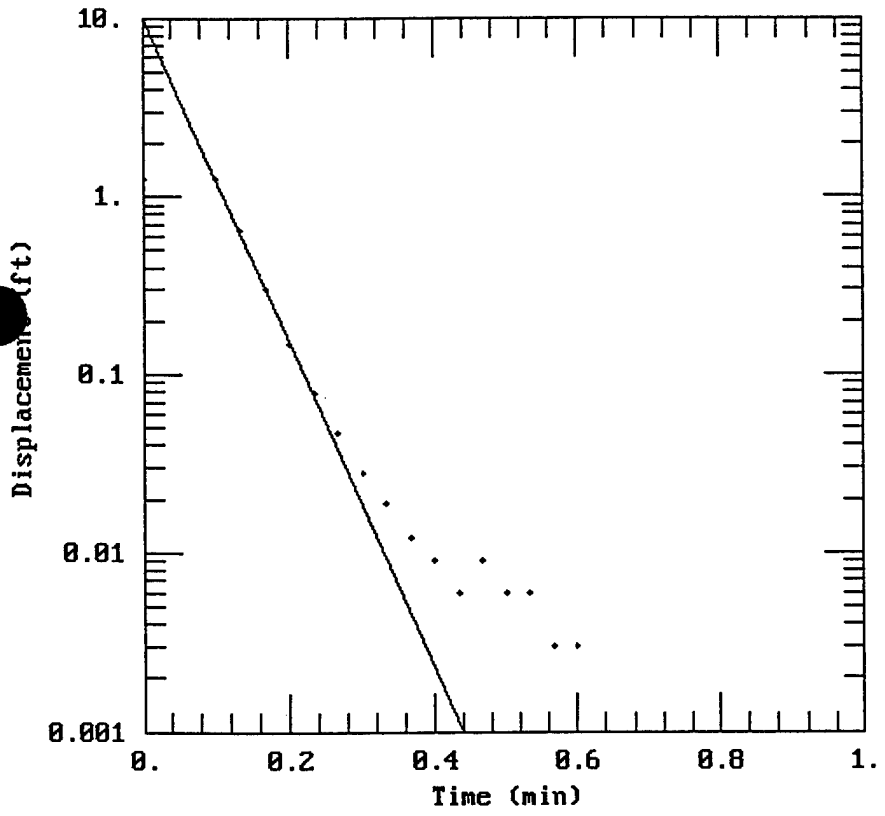
TEST DATA:
H0= 0.282 ft
r_c= 0.083 ft
r_w= 0.271 ft
L = 15. ft
b = 80. ft
H = 15. ft

PARAMETER ESTIMATES:
K = 0.03038 ft/min
y0 = 8.522 ft

AQTESOLV

CLIENT: AFCEE	COMPANY: Parsons E.S.
LOCATION: Shaw AFB, South Carolina	PROJECT: 722450.37020

MW-112 Rising Head Test 1



DATA SET:
MW112B.DAT
06/06/97

AQUIFER MODEL:
Unconfined

SOLUTION METHOD:
Bouwer-Rice

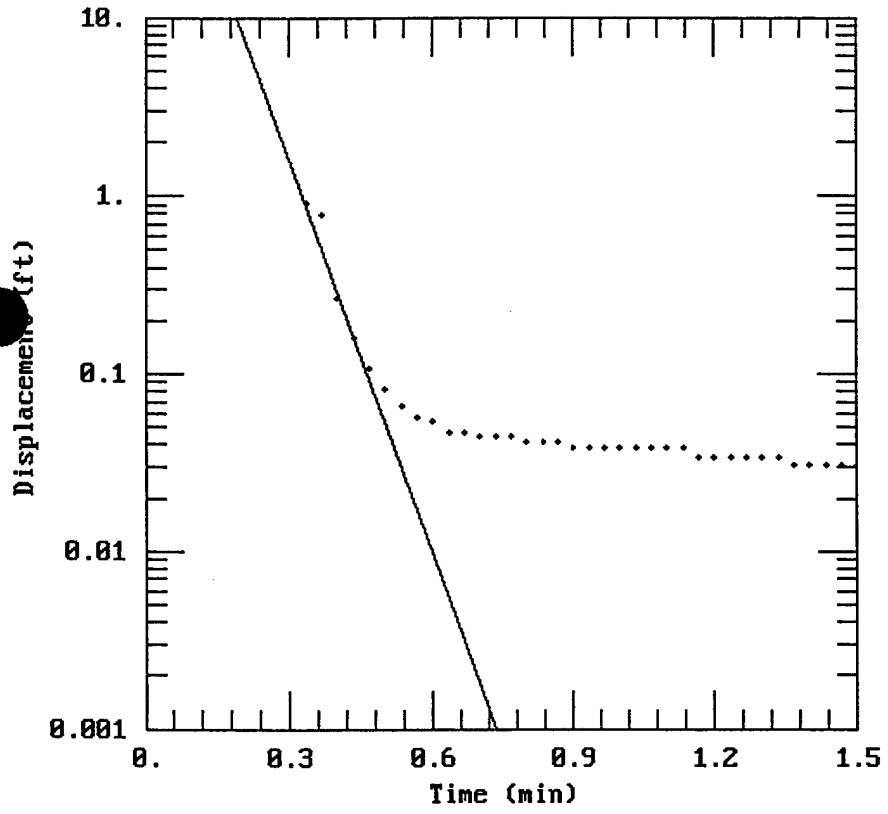
TEST DATA:
H0= 1.241 ft
r_c= 0.083 ft
r_w= 0.271 ft
L = 15. ft
b = 80. ft
H = 15. ft

PARAMETER ESTIMATES:
K = 0.04883 ft/min
y0 = 9.81 ft

AQTESOLV

CLIENT: AFCEE	COMPANY: Parsons E.S.
LOCATION: Shaw AFB, South Carolina	PROJECT: 722450.37020

MW-112 Falling Head Test 2



DATA SET:
MW112C.DAT
06/06/97

AQUIFER MODEL:
Unconfined

SOLUTION METHOD:
Bouwer-Rice

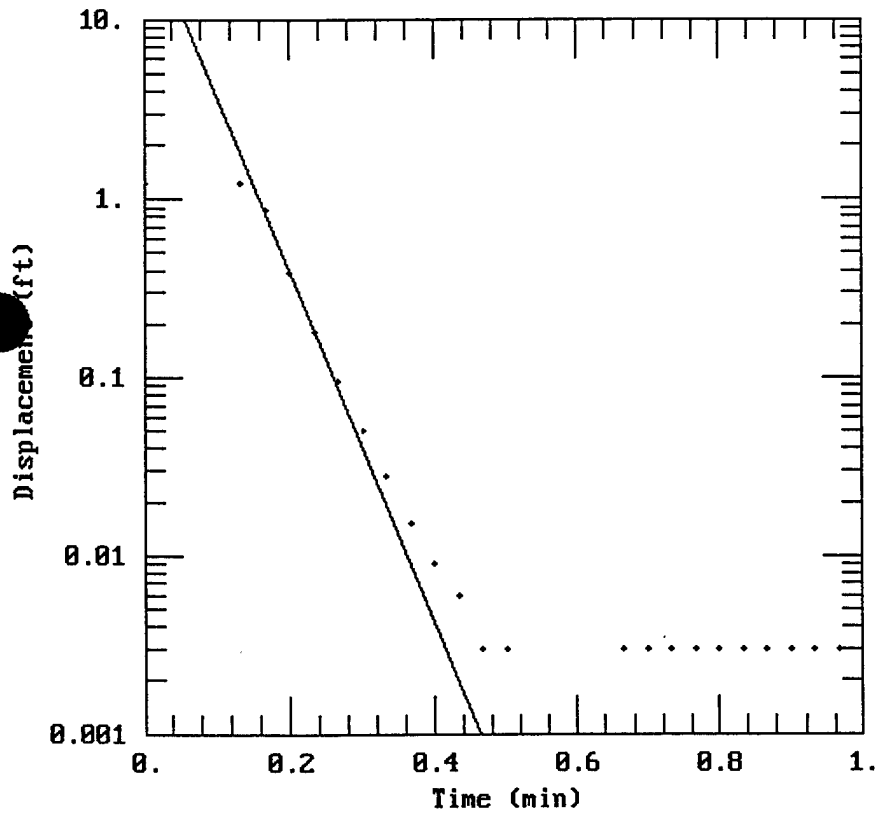
TEST DATA:
H0= 0.89 ft
r_c= 0.083 ft
r_w= 0.271 ft
L = 15. ft
b = 80. ft
H = 15. ft

PARAMETER ESTIMATES:
K = 0.03949 ft/min
y0 = 243.9 ft

AQTESOLV

CLIENT: AFCEE	COMPANY: Parsons E.S.
LOCATION: Shaw AFB, South Carolina	PROJECT: 722450.37020

MW-112 Rising Head Test 2



DATA SET:
MW112D.DAT
06/06/97

AQUIFER MODEL:
Unconfined
SOLUTION METHOD:
Bouwer-Rice

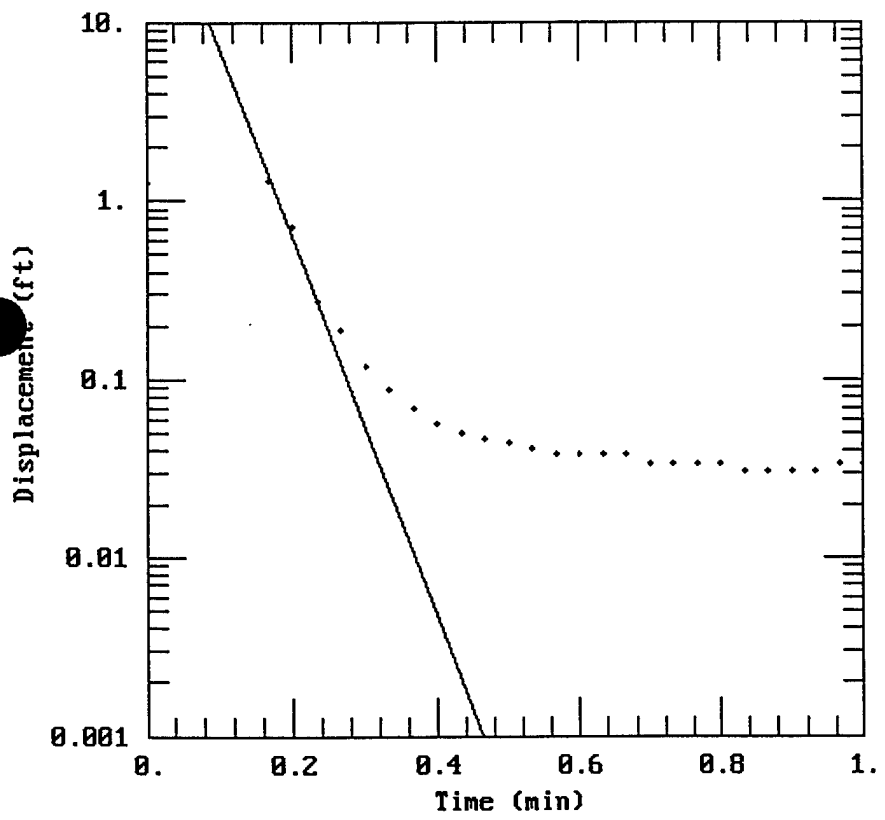
TEST DATA:
H0= 1.216 ft
r_c= 0.083 ft
r_w= 0.271 ft
L = 15. ft
b = 80. ft
H = 15. ft

PARAMETER ESTIMATES:
K = 0.05301 ft/min
y0 = 37.58 ft

AQTESOLV

CLIENT: AFCEE	COMPANY: Parsons E.S.
LOCATION: Shaw AFB, South Carolina	PROJECT: 722450.37020

MW-112 Falling Head Test 3



DATA SET:
MW112E.DAT
06/06/97

AQUIFER MODEL:
Unconfined

SOLUTION METHOD:
Bouwer-Rice

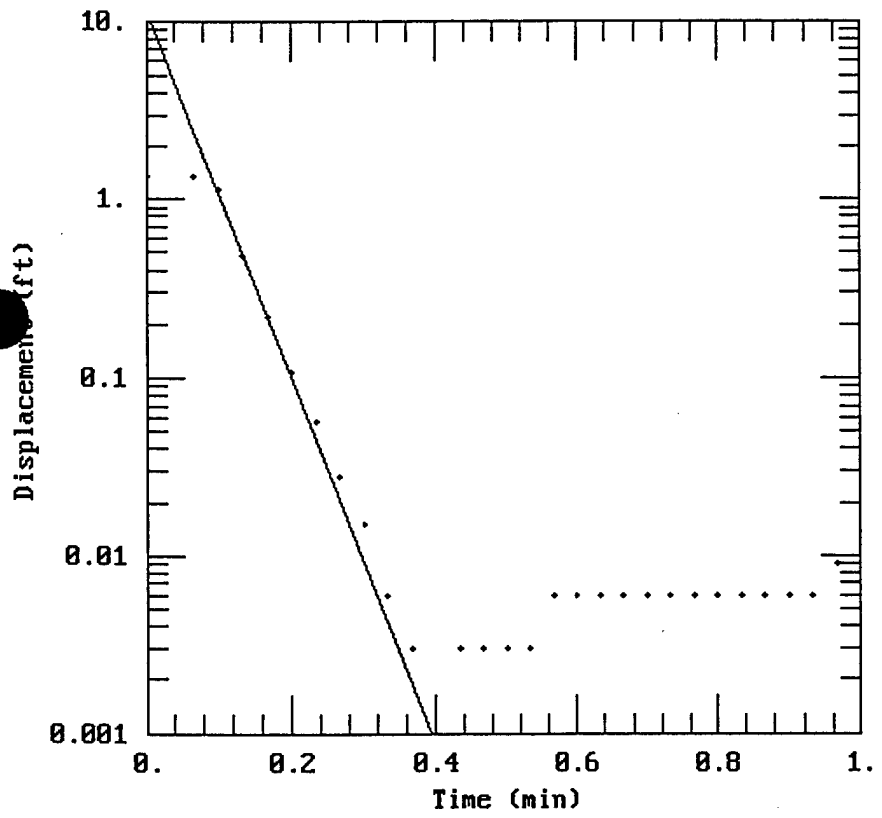
TEST DATA:
H0= 1.246 ft
r_c= 0.083 ft
r_w= 0.271 ft
L = 15. ft
b = 80. ft
H = 15. ft

PARAMETER ESTIMATES:
K = 0.05688 ft/min
y0 = 82. ft

AQTESOLV

CLIENT: AFCEE	COMPANY: Parsons E.S.
LOCATION: Shaw AFB, South Carolina	PROJECT: 722450.37020

MW-112 Rising Head Test 3



DATA SET:
MW112F.DAT
06/06/97

AQUIFER MODEL:
Unconfined

SOLUTION METHOD:
Bouwer-Rice

TEST DATA:
H0= 1.353 ft
r_c= 0.083 ft
r_w= 0.271 ft
L = 15. ft
b = 80. ft
H = 15. ft

PARAMETER ESTIMATES:
K = 0.05553 ft/min
y0 = 11.66 ft

AQTESOLV

Date:	11 Dec 97
Number of pages including cover sheet:	2

FAX

Best Environmental Flight in the Air Force 1994

To:	Parsons ES
	Attn: Todd Harrington
Phone:	303-831-8100
FAX #	1 303-831-8208

From:	Richard Keller
	20 CES/CEV
	345 Cullen Street
	Shaw AFB SC 29152-5126
Phone:	(803) 668-5213
FAX #	(803) 668-4383

X	Routine		Urgent		Review Comment		For Your Information		Please Reply

SUBJECT: WELL INFORMATION

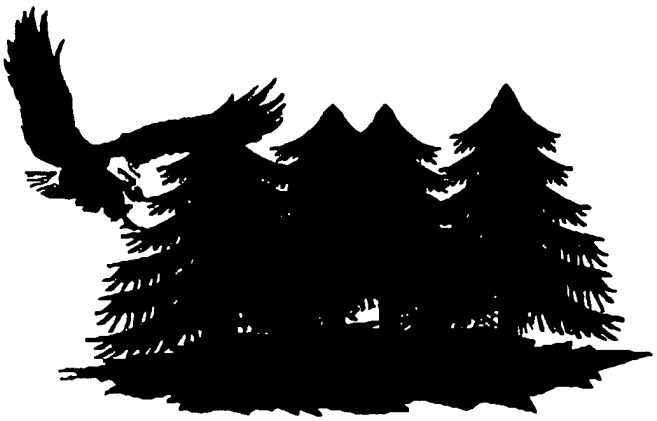
Remarks:

Will try to send a more clear copy late today

Thanks,

Richard C Keller

Releaser's Signature



	Date:	11 June 97
	Number of pages including cover sheet:	2

FAX

To:	Craig Harron or Todd Herrington
	Parsons Engineering
Phone:	303-831-8100, ext1956
FAX #	303-831-8208

From:	Michael Acorn
	20 CES/CEV
	345 Culle Street
	Shaw AF SC 29152-5126
Phone:	(803) 668-5213, DSN 965-5207
FAX #	(803) 668-4383

SUBJECT: Forwarding well construction info for MW 106 and 112.

Remarks: Sorry for the delay; couldn't get a line off base.

Thanks,

Releaser's Signature

P.02
20 CES/CEV
8036684383
06-11-1997 14:41

Location	Well ID	State Plane Coordinates (Nad 83) North	East	Date Installed	Drilling Company	Aquifer*	Ground Elevation (ft msl)	TOC Elevation (ft msl)	Stick-Up (Feet)	TD BGS (ft)	Screen Length (ft)	Screened Interval BGS (ft) Top	Bottom	Bore Diameter (in)	CD (in)
OU#2B	MW-70B				Geo-Tech					210	10	200.0	210.0	8	2
OU#2C	MW-65A	775372.5035	2155157.43			LS		271.9							
OU#2C	MW-66A	776088.1763	2154649.19			LS		288.83							
OU#2C	MW-67A	777058.5003	2155404.63			LS		283.18							
OU#4	MW-105	782128.419	2166707.03			WT2/U	212.92	214.87	1.95	19.7	5	14.7	19.7		2
OU#4	MW-105D	782134.801	2166707.44			BC/L	212.92	215.11	2.19	176.5	10	164.0	174.0		2
OU#4	MW-106	782452.344	2166601.96			WT2/U	217.63	219.21	1.58	24.3	5	19.3	24.3		2
OU#4	MW-106D	782448.677	2166595.26			BC/L	217.47	218.99	1.52	179.5	10	167.0	177.0		2
OU#4	MW-107	782281.684	2166296.11			WT2/U	213.21	214.79	1.58	19.9	5	14.9	19.9		2
OU#4	MW-111	782234.008	2165810.28			WT2/U	220.56	221.86	1.3	21.5	5	16.5	21.5		2
OU#4	MW-112	782153.317	2166456.63			WT2/U	215.78	218.01	2.23	25	15	10.0	25.0		2
OU#4	MW-112A	782153.806	2166465.88			WT2/L	215.78	217.92	2.14	89.7	9.54	79.6	89.2		2
OU#4	MW-112D	782159.916	2166459.51			BC/L	215.78	217.73	1.95	155.2	10	142.7	152.7		2
OU#4	MW-113	782498.827	2166473.27			WT2/U	206.79	208.95	2.16	25	15	5.0	20.0		2
OU#4	MW-113A	782490.479	2166472.45			WT2/L	207.07	209.22	2.15	35	15	20.0	35.0		2
OU#4	MW-114	782369.261	2166797.62			WT2/U	204.83	207.1	2.27	25	15	5.0	20.0		2
OU#4	MW-115	781886.414	2166877.51			WT2/U	201.92	204.19	2.27	25	15	3.0	18.0		2
OU#4	MW-115A	781888.874	2166869.61			WT2/L	202.19	204.16	1.97	69.08	9.51	59.1	68.6		2
OU#4	MW-116	781981.943	2166241.08			WT2/U	217.20	219.46	2.26	25.6	14.51	8.3	22.8		2
OU#4	MW-116A	781982.286	2166251.07			WT2/L	217.14	219.48	2.34	94.74	9.54	85.2	94.7		2
OU#4	MW-117	781914.192	2166673.36			WT2/U	213.89	216.42	2.53	21.41	14.45	6.5	20.9		2
OU#4	MW-118	781610.669	2166979.11			WT2/U	201.12	203.51	2.39	10.36	9.51	0.9	10.4		2
OU#4	PZ-101	781665.342	2166718.03			WT2/U	218.53	220.33	1.8	30	10	20.0	30.0		2
OU#4	PZ-102	781686.963	2166705.66			WT2/U	218.53	220.19	1.66	28	10	18.0	28.0		2
OU#4	PZ-103	781622.498	2166741.98			WT2/U	218.63	220.94	2.31	35	10	25.0	35.0		2
OU#4	M1P1			9/12/96	Geo-Tech	Duplin				35	25	10.0	35.0	10	2
OU#4	M2														
OU#4	TW-101	781707.969	2166693.13			WT2	218.08	220.47	2.39	60	30	20.0	50.0		4
OU#5 FFTA3	FT2MW-1	779003.29	2163223.55			WT2/U	226.56	229.59	3.03	26	9.51	14.7	24.2		2
OU#5 FFTA3	FT2MW-10	778780.952	2163123.60			WT2/U	226.45	229.45	3	25	9.53	13.7	23.3		2
OU#5 FFTA3	FT2MW-2	778303.598	2163161.72			WT2/U	224.09	227.05	2.96	24	9.57	13.4	23.0		2
OU#5 FFTA3	FT2MW-3	778180.995	2163352.14			WT2/U	222.03	225.06	3.03	20	9.54	8.1	17.6		2
OU#5 FFTA3	FT2MW-4	778273.665	2163898.15			WT2/U	218.33	221.28	2.95	20	9.6	7.3	16.9		2
OU#5 FFTA3	FT2MW-5	778711.639	2163876.21			WT2/U	220.77	223.63	2.86	22	9.54	10.3	19.8		2
OU#5 FFTA3	FT2MW-6	778496.04	2163399.57			WT2/U	223.00	225.99	2.99	25	9.55	10.4	20.0		2
OU#5 FFTA3	FT2MW-7	778721.444	2163531.34			WT2/L	223.24	226.36	3.12	84	9.43	69.6	79.1		2
OU#5 FFTA3	FT2MW-8	779000.176	2163703.63			WT2/U	222.76	225.64	2.88	23	9.53	11.0	20.5		2
OU#5 FFTA3	FT2MW-9	778713.451	2163524.17			WT2/U	223.34	226.38	3.04	24	14.49	8.1	22.6		2

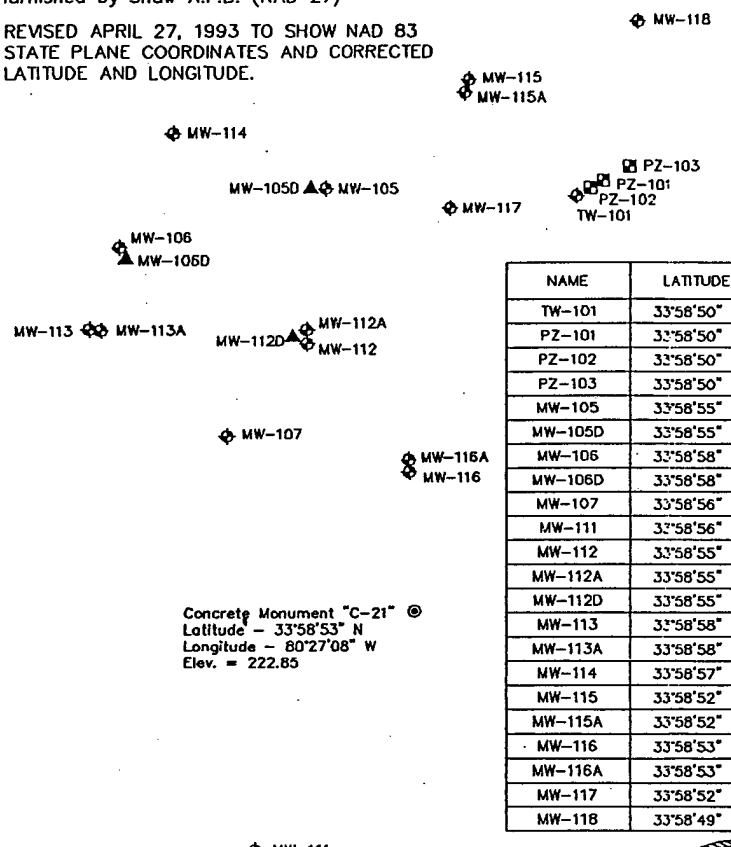
SUBJECT: Parsons ES Request for Well Elevations

1. Need Top of Casing + Coordinates for
TW-120 } @ OU-4
TW-121 }
MW 1602-21 @ OU-7
MW #4 & #7 @ ST-30 Bldg 1613

		TOC	~~EASTING~~ NORTHING	~~NORTHING~~ EASTING	
OU-4	TW-120	197.64	78 2021	216 7099	
	TW-121	198.01	781842	2167084	
BLDG 1613	MW1613-4	252.29	781790.039	2159779.430	~~NAD7~~ NAD8
	MW1613-7	252.83	781869.579	2159721.743	
Bldg 1602	MW 1602-21	250.86	781664.93	2159985.88	

Data on Concrete Control Monuments by Hoffman & Company, Inc.
furnished by Shaw A.F.B. (NAD 27)

REVISED APRIL 27, 1993 TO SHOW NAD 83
STATE PLANE COORDINATES AND CORRECTED
LATITUDE AND LONGITUDE.



LEGEND

- ◉ — Concrete Control Monument
- ✥ — Shallow Aquifer Monitoring Well
- ⧈ — Piezometer
- ▲ — Deep Monitoring Well

* Grade elevation (no concrete)

NAME	LATITUDE	LONGITUDE	NORTHING	EASTING	ELEV. (top of casing)	ELEV. (top of concrete)	ELEV. (ground)
TW-101	33°58'50" N	80°27'00" W	781707.969	2166693.132	220.47	218.08	218.08
PZ-101	33°58'50" N	80°27'00" W	781665.342	2166718.029	220.33	218.53	218.53
PZ-102	33°58'50" N	80°27'00" W	781686.963	2166705.655	220.19	218.53	218.53
PZ-103	33°58'50" N	80°27'00" W	781622.498	2166741.982	220.94	218.63	218.63
MW-105	33°58'55" N	80°27'00" W	782128.419	2166707.029	214.87	213.06	212.92
MW-105D	33°58'55" N	80°27'00" W	782134.801	2166707.444	215.11	213.31	212.92
MW-106	33°58'58" N	80°27'01" W	782452.344	2166601.959	219.21	217.63	217.63
MW-106D	33°58'58" N	80°27'01" W	782448.677	2166595.258	218.99	217.75	217.47
MW-107	33°58'56" N	80°27'05" W	782281.684	2166296.107	214.79	213.21 *	213.21
MW-111	33°58'56" N	80°27'13" W	782234.008	2165610.262	227.08	225.55	225.35
MW-112	33°58'55" N	80°27'03" W	782153.317	2166456.628	218.01	215.92	215.78
MW-112A	33°58'55" N	80°27'03" W	782153.806	2166465.881	217.92	216.02	215.78
MW-112D	33°58'55" N	80°27'03" W	782159.916	2166459.506	217.73	216.10	215.78
MW-113	33°58'58" N	80°27'03" W	782498.827	2166473.268	208.95	206.79	206.79
MW-113A	33°58'58" N	80°27'03" W	782490.479	2166472.454	209.22	207.07	207.07
MW-114	33°58'57" N	80°26'59" W	782369.261	2166797.623	207.10	204.83	204.83
MW-115	33°58'52" N	80°26'58" W	781886.414	2166877.511	204.19	201.92	201.92
MW-115A	33°58'52" N	80°26'58" W	781888.874	2166869.608	204.16	202.35	202.19
MW-116	33°58'53" N	80°27'05" W	781981.943	2166241.078	219.46	217.20	217.20
MW-116A	33°58'53" N	80°27'05" W	781982.286	2166251.067	219.48	217.14	217.14
MW-117	33°58'52" N	80°27'00" W	781914.192	2166673.356	216.42	213.89	213.89
MW-118	33°58'49" N	80°26'57" W	781610.669	2166979.110	203.51	201.30	201.12

SCALE: 1" = 200'

0 100' 200' 400' 600' 800'

CARL J. CROFT REGISTERED LAND SURVEYOR No. 4215 SOUTH CAROLINA

MONITORING WELL LOCATIONS AT SHAW A.F.B.

Prepared for Rust Enviromental & Infrastructure

(803) 773-1631
CROFT Engineering Company
418 N. Liberty St., Sumter, S.C. 29150

DR: DET-CAD	DATE: Mar. 17, 1993	SHEET NO. 1
DES: CJC	JOB NO. 93024	OF 1
APVD:		

APPENDIX B

SOIL, SEDIMENT, GROUNDWATER, AND SURFACE WATER ANALYTICAL RESULTS COLLECTED AS PART OF THIS TS.

MANTECH
POST OFFICE BOX 1198
ADA, OK 74820

FAX PHONE:
405-436-8501

VERIFICATION PHONE:
405-436-8660

DATE: 6/19/97 **#PAGES (INCLUDING COVER SHEET)** 2

TO: Craig Harran

PHONE: _____ **FAX:** 303-831-8208

FROM: Sharon Hightower

PHONE: 405-436-8664 or 436-8682

COMMENTS: _____

Vanver (303) 831-8208 Craig Harran

SERVICE REQUEST

Robert S. Kerr Environmental Research Laboratory
U.S. ENVIRONMENTAL PROTECTION AGENCY
Ada, Oklahoma 74820

Rev.10/02/96

EPA CONTRACT NO. 68-C3-0322
CONTRACTOR: ManTech
W.A.NO. WA-03-SF-101
S.R.NO. SF-3-266
AMEND.NO. 0
EST. START DATE 5/14/97
EST. END DATE 6/20/97
ISSUE DATE 4/25/97

PROJECT PLAN TITLE: Shaw AFB
PROJECT NUMBER: RPDK 2
SPRD TEAM: Natural Attenuation
ORIGINATOR'S SIGNATURE Don Kampbell

LAB/DIVISION/BRANCH NRMRL/SPRD/ BPAB

CONTRACT PERIOD 3 07/15/93 - 09/30/94 =0 10/01/94 - 09/30/95 =1

10/01/95 - 09/30/96 =2 10/01/96 - 09/30/97 =3 10/01/97 - 06/30/98 =4

TASK AREA(S):

___SAMPLE MANAGEMENT/COORDINATION
✓ ROUTINE ANALYSES
___SPECIAL ANALYSES
___DATA INTERPRETATION/ANALYSIS
___TECHNICAL SUPPORT
___METHODS DEVELOPMENT/MODIFICATION
___SYSTEMS DEVELOPMENT/MODIFICATION
___SPECIAL REPORTS/PUBLICATIONS
___MEETING ATTENDANCE/PRESENTATION

TASKS DESCRIPTION (INCLUDES SAMPLES, ANALYSES, METHODS, ETC.):

50 ground water samples for nitrate + nitrite, chlorides, surfate, TOC, ammonia, BTEXXXBTM, fuel carbon, chlorinated VOA's, and dissolved gases (methane, ethene, ethane).

2 water samples for semivolatile organics.
4 water samples for volatile organic acids.
1 floating product for compound I.D.
18 core samples for TOC, moisture.

Please submit report copies to: _____

MILESTONE(S)	DUE DATE
Report	6/20/97

EPA WAM(APPROVAL) Garmon Smith DATE: 4/28/97
EPA P.O. (CONCURRENCE) _____ DATE: _____
CONTRACTOR PROJECT MANAGER Steve Vandergrass DATE: 4/28/97
ANALYST Sharon Hightower Mark White DATE: 4-28-97
Mark Blankenship
John Allen David Jim Hopkins SV for Lisa Black
David A. Forace Dennis Dine
Steve Vandergrass
Mark White
436-8909 436-8663

MANTECH Environmental Technology

Don Kampbell

Ref: 97-DK16/vg
July 2, 1997

405-332-8500
405-436-8564

Dr. Don Kampbell
National Risk Management Research Laboratory
Subsurface Protection & Remediation Division
U.S. Environmental Protection Agency
P.O. Box 1198
Ada, OK 74820

compound identification
→ meas concentrations

THRU: S.A. Vandegrift

Dear Dr. Kampbell:

This report contains the results of my GC/MSD analysis of the following samples from Shaw AFB under Service Request #SF-3-266:

I. Floating product samples
1. OU-4 MPB
2. OU-4 MPC
3. MW1613-12

for compound identification by mass spectral library searching and chromatography of known standards. TIC chromatograms are also included.

II. Methylene chloride core extracts
1. SED-1
2. SED-2
3. SED-3
4. SED-4
5. SED-5

for quantitative determination of benzene, toluene, ethylbenzene, xylene isomers, trimethylbenzene isomers and trichloroethylene.

Chromatographic separation for purposes of mass spectral library identification was performed using a 30m X 0.25mm Restek "Stabilwax" capillary column in series with a 100m X 0.25mm J&W DB-1 "Petrocol" capillary column (total length = 130m, both 0.5um film). A 0.1 µl volume was injected on-column. The mass spectral scan range was m/z=39-350. The sample was diluted 1:40 with methylene chloride prior to analysis. Many sample peaks identified by mass spectral library search were verified using the following petroleum compound mixtures: n-paraffins (11 compounds), isoparaffins (35 compounds), naphthenes (29 compounds), aromatics (37 compounds) and PNAs (3 compounds). The floating product samples were received on May 22, 1997 and stored in the freezer until analysis on June 19-20, 1997.

The methylene chloride core extracts were chromatographed using a 30m X 0.25mm Restek "Stabilwax" (Crossbonded Carbowax-PEG, 0.5µm film)

capillary column with a SGE Carbowax deactivated Megabore precolumn. SIM mode was used with the ions chosen from those listed in EPA method 524.2 Revision 3.0. Multiple ions were acquired and ion ratios used to verify the accuracy of target compound identification. Standards calibration ranged from 0.025 to 250 µg/ml. Complete reports detailing the acquisition method and calibration curves have been recorded. The sample extracts were received on May 22, 1997 and analyzed on June 30, 1997.

If you require further information, please feel free to contact me.

Sincerely,

David A. Kovacs

xc: R.L. Cosby
G.B. Smith
J.L. Seeley

Sample	Benzene	TCE	Toluene	EB	p-X	m-X	o-X	1,3,5-TMB	1,2,4-TMB	1,2,3-TMB
SED-1	ND	3.51E-02	6.22E-02	ND	ND	2.06E-02	ND	ND	ND	ND
SED-2	ND	2.41E-02	5.17E-02	BLQ	ND	BLQ	BLQ	ND	ND	ND
SED-3	2.08E-02	6.35E-02	9.69E-02	BLQ	2.12E-02	3.58E-02	2.92E-02	ND	BLQ	BLQ
SED-4	BLQ	6.44E-02	8.77E-02	ND	ND	1.79E-02	ND	ND	ND	ND
SED-5	ND	7.98E-02	1.26E-01	ND	ND	3.93E-02	ND	ND	ND	ND
Check Standards (ug/ml)										
QC	4.55E+01	0.00E+00	5.99E+01	5.91E+01	5.95E+01	4.56E+01	5.59E+01	4.60E+01	4.61E+01	5.22E+01
QC (expected)	5.00E+01	N/A	6.00E+01	6.00E+01	6.00E+01	5.00E+01	6.00E+01	5.00E+01	5.00E+01	5.00E+01
2.5	2.43E+00	2.41E+00	2.63E+00	2.27E+00	2.27E+00	2.29E+00	2.33E+00	2.48E+00	2.42E+00	2.55E+00
Method Blank 5-27-97	7.47E-02	8.03E-01	1.34E+00	BLQ	BLQ	2.31E-01	BLQ	ND	ND	ND
$MeCl_2$ Blank	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

Note: Significant levels of TCE, Toluene and m-Xylene were found in the Method Blank. Sample values may be false positives.

MANTECH

Ref: 97\LB35

June 3, 1997

Dr. Don Kampbell
National Risk Management Research Laboratory
Subsurface Protection and Remediation Division
U.S. Environmental Protection Agency
P.O. Box 1198
Ada, OK 74820

THRU: S.A. Vandegrift SV

Dear Don:

Please find attached the analytical results for Service Request SF-3-266, Shaw AFB, requesting the analysis of ground water samples to be analyzed by purge-and-trap/GC-PID:FID for Benzene, Toluene, Ethylbenzene, p-, m-, & o-Xylene, 1,3,5-, 1,2,4-, & 1,2,3-Trimethylbenzene, and Total Fuel Carbon. We obtained the 55 aqueous samples, in duplicate, in capped, 40 mL VOA autosampler vials May 22, 1997 and they were analyzed May 29-June 2, 1997. The samples were acquired and processed using the Millennium data system. A 6 place (1-1000 ppb) external calibration curve was used to quantitate sample concentration for all the compounds of interest.

RSKSOP-122, "Analysis of Volatile Aromatic Hydrocarbons with Separation of Xylene Isomers by Purge & Trap Gas Chromatography" was used for these analyses. Autosampling was performed using a Dynatech Precision autosampler system in line with a Tekmar LSC 2000 concentrator.

Sincerely,

Lisa R. Black

Lisa R. Black

xc: R.L. Cosby
G.B. Smith
J.T. Wilson
J.L. Seeley JB

Shaw AFB GW Analyses Presented to Dr. Kampbell

Units = ng/mL ug/L Analyst: L. Bla...

SampleName	BENZENE	TOLUENE	ETHYLBENZENE	p-XYLENE	m-XYLENE	o-XYLENE	1,3,5-TMB	1,2,4-TMB	1,2,3-TMB	Fuel Carbon
100 PPB	95.9	103	109	109	110	107	116	113	110	N/A
QC, OBSERVED, PPB	48.8	50.6	50.6	54.7	53.0	53.5	57.2	56.7	49.3	N/A
QC, TRUE VALUE, PPB	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	N/A
MW1613-1	207	BLQ	28.0	17.1	BLQ	15.5	15.9	69.5	27.5	924
MW1613-1 Duplicate	201	BLQ	26.1	15.8	BLQ	14.4	14.7	65.9	25.9	881
MW1613-2	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MW1613-3	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MW1613-3A	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MW1613-4	1330	903	444	390	543	444	151	441	175	6470
MW1613-4A	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MW1613-5	1632	984	320	332	551	427	92.9	295	121	5810
MW1613-6	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MW1613-7	7.8	26.4	22.4	23.5	48.2	25.2	33.5	101.7	47.5	2330
10 PPB	9.4	10.1	10.5	10.3	10.5	10.1	10.6	10.4	10.2	N/A
MW1613-8	975	570	87.7	96.4	233	151	21.6	75.1	45.9	3050
MW1613-9	594	551	189	217	331	350	100	222	127	3930
MW1613-9 Duplicate	702	659	216	243	374	412	112	253	143	4240
MW1613-9A	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MW1613-10	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MW1613-11	1202	1042	364	309	744	486	99.0	300	162	6310
MW1613-12	58.3	8.5	80.2	60.7	136	78.4	45.6	178	99.5	1330
MW1613-12rinse	BLQ	3.3	ND	ND	BLQ	ND	ND	1.0	BLQ	44.3
MW1613-13	2.5	BLQ	BLQ	BLQ	1.0	BLQ	1.8	1.3	1.5	117
MW1613-13A	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MW1613-14	BLQ	ND	ND	ND	BLQ	ND	ND	ND	ND	BLQ
500 PPB	465	457	452	451	450	454	455	454	460	N/A
MW1613-14A	ND	ND	ND	ND	BLQ	BLQ	ND	ND	ND	BLQ
MW1613-15	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MW1613-15A	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MW1613-16	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MW1613-16 Duplicate	ND	ND	ND	ND	BLQ	ND	ND	ND	ND	BLQ
MPA	14.5	943	403	388	922	624	152	321	206	5540
MPB	7.1	917	224	228	548	325	118	326	144	4130
MPC	81.7	1685	242	254	638	387	118	328	148	4730
MPD	19.3	159	142	142	232	122	40.4	204	44.9	1720
MPE	ND	ND	ND	BLQ	BLQ	ND	ND	ND	ND	BLQ

ND = None Detected; BLQ = Below Limit of Quantitation, 1 ppb; N/A = Not Analyzed

Prin[redacted]3/97 SF-3-266 Shaw AFB GW Ana[redacted] Presented to Dr. Kampbell Units = ng/mL [redacted]t: L. Blac..

SampleName	BENZENE	TOLUENE	ETHYLBENZENE	p-XYLENE	m-XYLENE	o-XYLENE	1,3,5-TMB	1,2,4-TMB	1,2,3-TMB	Fuel Carbon
QC, OBSERVED, PPB	46.3	47.7	46.8	54.0	52.5	49.6	51.9	52.0	45.8	N/A
QC, TRUE VALUE, PPB	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	N/A
TMP-1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
TMP-2	12.5	2.3	2.4	2.8	0.9	1.0	0.9	4.2	9.7	127
TMP-3	12.4	ND	ND	ND	ND	2.2	ND	ND	4.5	60.4
TMP-4	10.1	BLQ	8.4	8.5	ND	ND	BLQ	13.2	BLQ	207
TMP-4 Duplicate	10.7	BLQ	8.9	8.3	ND	ND	BLQ	13.8	0.9	197
TMP-5	28.2	9.9	77.2	70.2	49.1	9.0	19.0	72.3	27.7	529
SWS-1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
SWS-2	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
SWS-2 Duplicate	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
SWS-3	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
SWS-4	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
SWS-5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
GC LAB BLANK, PPB	ND	ND	ND	ND	ND	ND	ND	ND	ND	N/A
1 PPB	0.9	0.8	0.9	0.9	1.0	0.8	0.8	0.8	0.8	N/A
TW-120	ND	2.1	ND	ND	ND	ND	ND	ND	ND	1.8
TW-121	5.3	1.2	1.0	1.2	0.9	1.9	ND	0.9	1.2	16.1
TW-101	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MW-105	70.7	7.1	37.9	92.5	65.7	66.7	3.5	137	52.7	930
MW-106	BLQ	BLQ	2.6	2.1	BLQ	BLQ	ND	2.8	ND	14.0
MW-107	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MW 107 Duplicate	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MW-111	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MW-112	229	438	495	501	1037	199	177	521	193	5080
MW-112A	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MW-113	ND	ND	BLQ	BLQ	0.9	ND	ND	ND	ND	BLQ
100 PPB	87.8	93.1	98.7	104	105	96.5	104	101	99.9	N/A
MW-114	6.3	12.2	56.8	57.9	103	59.0	14.3	74.9	20.3	623
MW-115	157	393	113	135	240	213	26.0	191	90.7	2350
MW-115A	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MW-116	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MW-116A	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MW-117	30.0	89.5	72.8	83.5	190	123	13.4	90.5	41.1	1290
MW 117 Duplicate	30.7	93.7	74.5	79.6	181	127	14.0	92.3	42.7	1280
MW-118	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
500 PPB	499	503	506	487	487	509	518	514	516	N/A

ND = None Detected; BLQ = Below Limit of Quantitation, 1 ppb; N/A = Not Analyzed

MANTECH

Ref: 97JAD31

June 3, 1997

Dr. Don Kampbell
National Risk Management Research Laboratory
Subsurface Protection and Remediation Division
U.S. Environmental Protection Agency
P.O. Box 1198
Ada, OK 74820

THRU: S.A. Vandegrift SV

Dear Don:

As requested in Service Request # SF-3-266, headspace GC/MS analysis of 55 Shaw AFB water samples for chlorinated volatile organics was completed. The samples were received on May 22, 1997 and analyzed on May 23-24 & 28-29, 1997. RSKSOP-148 (Determination of Volatile Organic Compounds in Water by Automated Headspace Gas Chromatography/Mass Spectrometry (Saturn II Ion Trap Detector) was used for this analysis.

An internal standard calibration method was established for the 15 compounds. The standard curves were prepared from 1.0 to 4000 ppb. The lower calibration limits were 1.0 ppb.

A dilution corrected quantitation report for the samples, lab duplicates, field duplicates, QC standards and lab blanks is presented in tables 1-3.

If you should have any questions, please feel free to contact me.

Sincerely,

John Allen Daniel

John Allen Daniel

xc: R.L. Cosby
G.B. Smith
D.D. Fine
J.L. Seeley
J.T. Wilson JB

Table 1. Quantitation Report for S.R. # SF-3-266 from Shaw AFB.

Concentration = ppb

Compound	MW1613 1	MW1613 2	1613 3	1613 3A	1613 4	MW1613 4A	MW1613 5	MW1613 6	MW1613 7	MW1613 8
VINYL CHLORIDE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,1-DICHLOROETHENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
T-1,2-DICHLOROETHENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,1-DICHLOROETHANE	ND	ND	ND	ND	ND	ND	ND	ND	ND	---
C-1,2-DICHLOROETHENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
CHLOROFORM	ND	ND	ND	ND	1.9	ND	1.4	ND	---	1.0
1,1,1-TRICHLOROETHANE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
CARBON TETRACHLORIDE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,2-DICHLOROETHANE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
TRICHLOROETHENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
TETRACHLOROETHENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
CHLOROBENZENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,3-DICHLOROBENZENE	1.2	---	---	---	ND	---	ND	---	ND	ND
1,4-DICHLOROBENZENE	---	---	---	---	---	ND	---	ND	ND	ND
1,2-DICHLOROBENZENE	---	---	---	---	ND	ND	ND	---	ND	ND

Compound	MW1613 8 Lab Dup	MW1613 8 Field Dup	MW1613 9	MW1613 9A	MW1613 10	MW1613 11	1613 12	1613 12 RINSE	MW1613 13	MW1613 13A
VINYL CHLORIDE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,1-DICHLOROETHENE	ND	ND	ND	ND	ND	ND	ND	ND	---	---
T-1,2-DICHLOROETHENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,1-DICHLOROETHANE	---	ND	---	ND	ND	ND	---	ND	ND	ND
C-1,2-DICHLOROETHENE	ND	ND	ND	ND	ND	ND	ND	ND	---	ND
CHLOROFORM	1.0	1.0	---	ND	ND	1.7	ND	1.3	ND	ND
1,1,1-TRICHLOROETHANE	ND	ND	ND	ND	ND	ND	ND	---	ND	ND
CARBON TETRACHLORIDE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,2-DICHLOROETHANE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
TRICHLOROETHENE	ND	ND	ND	ND	ND	ND	ND	---	---	ND
TETRACHLOROETHENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
CHLOROBENZENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,3-DICHLOROBENZENE	ND	ND	ND	---	---	ND	ND	ND	ND	ND
1,4-DICHLOROBENZENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,2-DICHLOROBENZENE	ND	ND	ND	---	---	ND	ND	ND	ND	ND

ND = None Detected --- = Below Calibration Limit(1.0 ppb) Dup = Duplicate

Table 2. Quantitation Report for S.R. # SF-3-266 from Shaw AFB.

Concentration = ppb

Compound	MW1613 14	MW1613 14A	MW1613 14A Lab Dup	MW1613 15	MW1613 15A	MW1613 16	MPA	MPB	MPC	MPC Field Dup 1/10 Dil
VINYL CHLORIDE	ND	ND	ND	ND	ND	ND	ND	ND	30.4	31.0
1,1-DICHLOROETHENE	ND	ND	ND	ND	ND	ND	4.3	4.7	748	727
T-1,2-DICHLOROETHENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,1-DICHLOROETHANE	ND	ND	ND	ND	ND	ND	30.8	15.4	1060	1030
C-1,2-DICHLOROETHENE	ND	ND	ND	ND	ND	ND	3.5	10.6	*****	4590
CHLOROFORM	ND	ND	ND	ND	ND	ND	2.0	---	1.2	ND
1,1,1-TRICHLOROETHANE	ND	ND	ND	ND	ND	ND	8.4	411	*****	23000
CARBON TETRACHLORIDE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,2-DICHLOROETHANE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
TRICHLOROETHENE	ND	ND	ND	ND	ND	ND	---	1.3	718	793
TETRACHLOROETHENE	ND	ND	ND	ND	ND	ND	ND	---	90.7	100
CHLOROBENZENE	ND	ND	ND	ND	ND	ND	ND	---	9.2	---
1,3-DICHLOROBENZENE	ND	ND	ND	ND	ND	ND	ND	1.1	14.1	11.0
1,4-DICHLOROBENZENE	ND	ND	ND	ND	ND	ND	ND	16.8	68.2	55.0
1,2-DICHLOROBENZENE	ND	ND	ND	ND	ND	ND	ND	13.5	117	95.0

	MPD	MPE	TMP-1 FT-1	TMP-2 OU4	TMP-2 OU4 Lab Dup	TMP-3 FT1/OU4	TMP-4 FT1	TMP-5 FT1	SWS-1	SWS-2
VINYL CHLORIDE	ND	ND	ND	22.8	22.4	59.6	7.7	116	ND	ND
1,1-DICHLOROETHENE	1.7	ND	ND	116	113	40.2	3.5	1.8	ND	ND
T-1,2-DICHLOROETHENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,1-DICHLOROETHANE	53.3	1.4	ND	1070	1030	1153	64.9	3.5	ND	ND
C-1,2-DICHLOROETHENE	155	4.9	ND	339	318	150	169	42.5	ND	---
CHLOROFORM	---	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,1,1-TRICHLOROETHANE	1.3	---	ND	78.6	116	60.5	---	ND	ND	ND
CARBON TETRACHLORIDE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,2-DICHLOROETHANE	ND	ND	ND	ND	ND	2.1	ND	ND	ND	ND
TRICHLOROETHENE	77.0	ND	ND	1.2	1.1	3.9	---	ND	ND	ND
TETRACHLOROETHENE	ND	ND	ND	---	---	1.0	ND	ND	ND	ND
CHLOROBENZENE	ND	ND	ND	---	---	---	ND	ND	ND	ND
1,3-DICHLOROBENZENE	ND	ND	ND	1.8	1.6	ND	---	ND	ND	ND
1,4-DICHLOROBENZENE	ND	ND	ND	5.6	5.3	3.3	2.2	ND	ND	ND
1,2-DICHLOROBENZENE	ND	ND	ND	10.5	9.8	6.3	2.5	ND	ND	ND

ND = None Detected --- = Below Calibration Limit(1.0 ppb) Dil = Dilution ***** = Above Calibration Limit(4000 ppb)

Table 3. Quantitation Report for S.R. # SF-3-266 from Shaw AFB.

Concentration = ppb

Compound	SWS-3	SWS-4	SWS-5	TM-120 FT1/OU4 1/10 Dil	TM-120 FT1/OU4 Field Dup	TM-121 FT1	TM-121 FT1 Lab Dup	TMP-101	MW 105	MW-106
VINYL CHLORIDE	ND	ND	ND	ND	ND	15.3	16.7	ND	1.2	ND
1,1-DICHLOROETHENE	---	ND	ND	ND	ND	7.3	7.7	ND	---	---
T-1,2-DICHLOROETHENE	ND	ND	ND	ND	ND	2.1	2.2	ND	ND	ND
1,1-DICHLOROETHANE	1.0	---	ND	ND	1.7	1.5	1.6	ND	---	3.0
C-1,2-DICHLOROETHENE	2.3	---	ND	ND	---	30.7	30.8	ND	201	5.9
CHLOROFORM	ND	ND	ND	ND	ND	ND	ND	ND	47.9	ND
1,1,1-TRICHLOROETHANE	---	ND	ND	ND	ND	ND	ND	ND	ND	ND
CARBON TETRACHLORIDE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,2-DICHLOROETHANE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
TRICHLOROETHENE	ND	ND	ND	ND	ND	ND	ND	ND	31.3	ND
TETRACHLOROETHENE	ND	ND	ND	ND	ND	ND	ND	ND	---	ND
CHLOROBENZENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,3-DICHLOROBENZENE	ND	ND	ND	ND	ND	---	---	ND	ND	ND
1,4-DICHLOROBENZENE	ND	ND	ND	ND	ND	---	---	ND	ND	ND
1,2-DICHLOROBENZENE	ND	ND	ND	ND	ND	1.7	1.8	ND	ND	ND

	MW-107	MW-111	MW-112	MW-112A	MW-113	MW-114	MW-115	MW-115 Lab Dup	MW-115 Field Dup 1/10 Dil	MW-115A
VINYL CHLORIDE	ND	ND	ND	ND	ND	ND	416	438	474	ND
1,1-DICHLOROETHENE	ND	ND	2.2	ND	ND	2.1	368	373	402	2.1
T-1,2-DICHLOROETHENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,1-DICHLOROETHANE	1.1	ND	64.8	ND	---	58.8	*****	*****	8700	---
C-1,2-DICHLOROETHENE	1.5	ND	22.0	ND	1.2	87.1	1620	1600	1740	ND
CHLOROFORM	ND	ND	2.3	ND	ND	---	---	---	---	ND
1,1,1-TRICHLOROETHANE	ND	ND	---	ND	ND	ND	2030	2460	2050	ND
CARBON TETRACHLORIDE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,2-DICHLOROETHANE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
TRICHLOROETHENE	ND	---	ND	ND	ND	ND	10.2	10.5	10.0	---
TETRACHLOROETHENE	ND	ND	ND	ND	ND	ND	4.8	4.9	ND	ND
CHLOROBENZENE	ND	ND	ND	ND	ND	ND	4.9	5.1	---	ND
1,3-DICHLOROBENZENE	ND	ND	ND	ND	ND	ND	11.6	12.2	11.0	ND
1,4-DICHLOROBENZENE	ND	ND	ND	ND	ND	ND	46.4	47.0	44.0	ND
1,2-DICHLOROBENZENE	ND	ND	ND	ND	ND	ND	88.9	93.7	83.0	ND

ND = None Detected --- = Below Calibration Limit(1.0 ppb) Dup = Duplicate Dil = Dilution

Table 4. Quantitation Report for S.R. # SF-3-266 from Shaw AFB.

Concentration = ppb

Compound	MW-116	MW-116A	MW-117	MW-117 Field Dup 1/10 Dil	MW-118	MW-118 Lab Dup	QC0523A 20 ppb	QC0523B 200 ppb	QC0523C 20 ppb	QC0523D 200 ppb
VINYL CHLORIDE	ND	ND	84.6	94.0	ND	ND	18.7	170	17.6	175
1,1-DICHLOROETHENE	ND	ND	148	159	ND	ND	23.3	223	22.1	223
T-1,2-DICHLOROETHENE	ND	ND	ND	ND	ND	ND	20.7	210	20.3	206
1,1-DICHLOROETHANE	ND	ND	481	509	ND	ND	21.0	206	21.4	210
C-1,2-DICHLOROETHENE	ND	ND	457	508	ND	ND	20.2	205	20.3	210
CHLOROFORM	ND	ND	---	ND	ND	ND	20.4	207	20.4	206
1,1,1-TRICHLOROETHANE	ND	ND	*****	4690	---	---	21.6	207	20.6	214
CARBON TETRACHLORIDE	ND	ND	ND	ND	ND	ND	20.8	204	19.5	207
1,2-DICHLOROETHANE	ND	ND	ND	ND	ND	ND	21.1	213	22.0	212
TRICHLOROETHENE	ND	ND	203	217	ND	ND	18.1	189	18.1	191
TETRACHLOROETHENE	ND	ND	24.1	25.0	ND	ND	21.5	205	20.5	204
CHLOROBENZENE	ND	ND	2.1	---	ND	ND	21.1	213	21.4	222
1,3-DICHLOROBENZENE	ND	ND	3.4	---	ND	ND	23.0	219	20.4	216
1,4-DICHLOROBENZENE	ND	ND	14.9	14.0	ND	ND	22.1	225	21.7	219
1,2-DICHLOROBENZENE	ND	ND	25.1	23.0	ND	ND	22.7	225	21.8	222

	QC0523E 20 ppb	QC0523F 200 ppb	QC0523G 20 ppb	QC0523H 200 ppb	QC0528I 200 ppb	QC0528J 20 ppb	QC0528K 200 ppb	QC0528L 20 ppb	QC0528M 200 ppb	BL0523A BLK
VINYL CHLORIDE	18.0	174	18.4	20.2	181	18.2	180	18.5	179	ND
1,1-DICHLOROETHENE	21.9	228	22.6	25.2	230	23.0	230	23.2	230	ND
T-1,2-DICHLOROETHENE	20.2	210	20.5	21.8	210	21.2	201	20.4	208	ND
1,1-DICHLOROETHANE	21.5	214	21.0	22.0	216	21.2	212	21.6	209	ND
C-1,2-DICHLOROETHENE	20.6	208	21.1	20.9	211	21.5	204	20.1	199	ND
CHLOROFORM	20.7	203	21.0	20.4	206	21.3	201	20.5	202	ND
1,1,1-TRICHLOROETHANE	20.9	214	20.5	22.7	218	21.8	215	20.8	218	ND
CARBON TETRACHLORIDE	20.4	209	20.3	22.7	209	21.2	211	20.7	213	ND
1,2-DICHLOROETHANE	22.2	210	21.1	22.3	209	22.5	203	20.8	206	ND
TRICHLOROETHENE	17.6	189	18.0	18.8	192	18.3	186	17.8	190	ND
TETRACHLOROETHENE	19.4	208	19.8	23.3	210	21.8	209	20.9	207	ND
CHLOROBENZENE	21.5	216	20.3	21.0	218	22.8	213	20.7	208	ND
1,3-DICHLOROBENZENE	18.9	213	18.6	20.2	217	20.6	209	19.5	210	ND
1,4-DICHLOROBENZENE	20.8	218	19.6	20.6	221	20.9	219	21.0	218	ND
1,2-DICHLOROBENZENE	20.2	221	19.7	20.1	226	21.5	215	20.6	220	ND

ND = None Detected --- = Below Calibration Limit(1.0 ppb) Dup = Duplicate QC = Quality Control Std. BL = Blank ***** = Above Calibration Limit(4000 ppb)

MANTECH

Ref: 97-SH33

June 2, 1997

Dr. Don Kampbell
National Risk Management Research Laboratory
Subsurface Protection & Remediation Division
U.S. Environmental Protection Agency
P.O. Box 1198
Ada, OK 74820

THRU: S.A. Vandegrift SV

Dear Don:

Attached are TOC results for 46 Shaw liquids submitted May 28, 1997 under Service Request #SF-3-266. Sample analysis was begun May 29, 1997 and completed June 2, 1997 using RSKSOP-102.

Blanks, duplicates, and AQC samples were analyzed along with your samples, as appropriate, for quality control. If you have any questions concerning this data, please feel free to ask me.

Sincerely,

Sharon Hightower

Sharon Hightower

xc: R.L. Cosby
G.B. Smith
J.L. Seeley JS

ManTech Environmental Research Services Corporation

R.S. Kerr Environmental Research Laboratory, P.O. Box 1198, 919 Research Drive
Ada, Oklahoma 74821-1189 405-436-8660 FAX 405-436-8501

KAMPBELL SHAW LIQUIDS SF-3-266

SAMPLE	MG/L TOC
TMP-1	1.74
TMP-2	2.85
TMP-3	1.76
TMP-4	2.71
MW105	22.2
MW106	1.93
MW107	1.66
MW111	1.37
MW112	22.0
DUP	22.0
MW112A	.884
MW113	1.43
MW114	2.78
MW115	8.59
MW115A	1.06
MW116	1.05
MW117	3.72
MW118	5.71
MW1613-1	1.75
MW1613-2	1.52
MW1613-3	.857
MW1613-3A	.814
MW1613-4	2.59
MW1613-4A	2.77
MW1613-5	50.9
DUP	51.3
MW1613-6	3.82
MW1613-7	1.24
MW1613-8	1.88
MW1613-9	1.96
MW1613-9A	1.27
MW1613-10	.740
MW1613-11	2.91
MW1613-12	4.65
MW1613-13	1.30
MW1613-13A	1.75
DUP	1.62
MW1613-14	.953
MW1613-14A	15.7
MW1613-15	.932
MW1613-15A	2.07
MW1613-16	1.24
MPA	144
MPB	5.27
DUP	5.77
MPC	7.75

SAMPLE	MG/L TOC
MPE	1.51
116A	.909
TW101	2.39
TW121	25.5
WSO38	4.75

WSO38 std t.v.=4.92

MANTECH

May 30, 1997

Dr. Don Kampbell
National Risk Management Research Laboratory
Subsurface Protection & Remediation Division
U.S. Environmental Protection Agency
P.O. Box 1198
Ada, OK 74820

THRU: S.A. Vandegrift SV

Dear Don:

Attached are TOC results for 5 Shaw soils submitted May 22, 1997 under Service Request #SF-3-266. Sample analysis was begun May 27, 1997 and completed May 30, 1997 using RSKSOP-102 and RSKSOP-120.

Blanks, duplicates, and AQC samples were analyzed along with your samples, as appropriate, for quality control. If you have any questions concerning this data, please feel free to ask me.

Sincerely,

Sharon Hightower

Sharon Hightower

xc: R.L. Cosby
G.B. Smith
J.L. Seeley JS

ManTech Environmental Research Services Corporation

R.S. Kerr Environmental Research Laboratory, P.O. Box 1198, 919 Research Drive
Ada, Oklahoma 74821-1189 405-436-8660 FAX 405-436-8501

KAMPBELL SHAW SOILS SF-3-266

SAMPLE	SOIL FILTRATE % O.C.	SOLIDS % TOC	TOTAL SOIL % TOC	MEAN %TOC	STD DEV
SED 1,1-1	.028	.522	.550	.389	.154
1-2	.028	.346	.374		
1-3	.031	.212	.243		
SED 2,1-1	.058	.956	1.01	1.09	.085
1-2	.066	1.11	1.18		
1-3	.070	1.02	1.09		
SED 3,1-1	.108	4.88	4.99	4.84	.240
1-2	.105	4.45	4.56		
1-3	.115	4.86	4.96		
SED 4,1-1	.028	.186	.214	.219	.010
1-2	.030	.200	.230		
1-3	.027	.185	.212		
SED 5,1-1	.043	10.70	10.74	10.89	.516
1-2	.040	10.42	10.46		
1-3	.047	11.41	11.46		
LECO STD		.934			
WSO38	4.60				

Leco soil std t.v.=.90+/-.04
WSO38 std t.v.=4.92

MANTECH

Ref: 97-BS3/vg
97-MAB6/vg

May 29, 1997

Dr. Don Kampbell
National Risk Management Research Laboratory
Subsurface Protection and Remediation Division
U.S. Environmental Protection Agency
P.O. Box 1198
Ada, OK 74820

THRU: Steve Vandegrift SV

Dear Don:

Please find attached the analytical results for Service Request #SF-3-124 requesting the analysis of 49 field samples for CO_2, Ferrous Iron, Total Alkalinity, Hydrogen Sulfide, Phenols, and Manganese. Samples were analyzed May 14, 15, 16, 17, 19, and 20, 1997.

Please note that samples with greater than 5.0 mg/l Ferrous Iron may have interfered with the Hach carbon dioxide color test. If you have any questions concerning these results, please feel free to contact us.

Sincerely,

Brad Scroggins

Mark Blankenship

xc: R.L. Cosby
G.B. Smith
J.L. Seeley

ManTech Environmental Research Services Corporation

R.S. Kerr Environmental Research Laboratory, P.O. Box 1198, 919 Research Drive
Ada, Oklahoma 74821-1189 405-436-8660 FAX 405-436-8501

Sample	CO_2 (mg/L)	Fe^{2+} mg/L	Total Alkalinity ($CaCO_3$) mg/L	H_2S mg/L	Phenols mg/L
MW 116μ	28	ND	10	<0.1	<0.1
MW 116	18	0.04	20	<0.1	<0.1
TW 101	50	0.84	50	<0.1	<0.1
MW 107	28	1.05	20	<0.1	<0.1
MW 106	32	3.00	20	0.1	<0.1
MW 105	88	3.08	20	<0.1	<0.1
MW 111	26	ND	10	<0.1	<0.1
MW 115	84	5.90	70	0.5	<0.1
MW 115A	22	0.08	10	<0.1	<0.1
2.0 ppm Std. Fe^{2+}	-----	1.94	----	-----	-----
MW 118	34	ND	30	<0.1	<0.1
MW 114	36	2.15	20	0.5	<0.1
MW 117	44	0.03	10	<0.1	<0.1
MW 112	120	7.00	60	0.5	<0.1
MW 112A	20	0.01	10	<0.1	<0.1
MW 113	22	0.13	10	<0.1	<0.1
MPC	70	4.00	30	0.3	<0.1
MPA	100	4.00	250	0.2	0.94
MW 1613-6	30	0.12	10	0.1	<0.1
MPB	28	3.00	30	2.0	<0.1
MW 1613-10	35	0.12	10	<0.1	<0.1
TMP-5	50	4.00	30	<0.1	<0.1
TMP-4	50	4.00	20	0.1	<0.1
MW 1613-2	35	0.12	10	<0.1	<0.1
MPE	50	7.00	30	<0.1	<0.1
MW 1613-3	30	0.03	20	<0.1	<0.1
TMP-3	40	0.18	10	<0.1	<0.1
TW-121	40	4.00	130	<0.1	<0.1
MW 1613-15	30	0.32	10	<0.1	<0.1
TMP-1	30	0.20	10	<0.1	<0.1
MW 1613-12	115	15.00	50	<0.1	<0.1
TMP-2	80	8.20	20	0.3	<0.1
MW 1613-8	80	6.90	90	<0.1	<0.1
MW 1613-9	40	21.00	70	0.1	<0.1
MW 1613-1	55	14.00	20	<0.1	<0.1
MW 1613-9A	35	ND	10	<0.1	<0.1
MW 1613-11	75	45.00	100	<0.1	<0.1
MW 1613-5A	30	0.13	10	<0.1	<0.1
MW 1613-5	70	4.00	100	<0.1	<0.1
MW 1613-7	55	9.00	20	<0.1	<0.1
MW 1613-3A	30	2.01	20	0.5	<0.1

Sample	CO_2 (mg/L)	Fe^{2+} mg/L	Total Alkalinity ($CaCO_3$) mg/L	H_2S mg/L	Phenols mg/L
MW 1613-4	50	8.40	100	<0.1	<0.1
MW 1613-13	70	0.09	10	<0.1	<0.1
MW 1613-13A	30	0.05	10	<0.1	<0.1
MW 1613-14	55	0.03	10	<0.1	<0.1
MW 1613-14A	10	0.09	110	0.3	<0.1
MW 1613-16	35	0.01	30	<0.1	<0.1
MW 1613-4A	30	0.03	20	0.3	<0.1

MANTECH

Ref: 97-MW42/vg
97-LP53/vg

May 29, 1997

Dr. Don Kampbell
National Risk Management Research Laboratory
Subsurface Protection & Remediation Division
U.S. Environmental Protection Agency
P.O. Box 1198
Ada, OK 74820

THRU: S.A. Vandegrift SV

Dear Don:

Attached are the results of 50 Shaw AFB samples submitted to MERSC as part of Service Request #SF-3-266. The samples were received May 22 and analyzed May 23 and 27, 1997. The methods used for analysis were EPA Methods 353.1 for NO_2 and NO_3 and 350.1 for NH_3, and Waters capillary electrophoresis Method N-601 for Cl and SO_4. Quality assurance measures performed on this set of samples included spikes, duplicates, known AQC samples and blanks.

If you have any questions concerning these results, please feel free to contact us.

Sincerely,

Mark White

Lynda Pennington
Lynda Pennington

xc: R.L. Cosby
G.B. Smith
J.L. Seeley SV for

ManTech Environmental Research Services Corporation

R.S. Kerr Environmental Research Laboratory, P.O. Box 1198, 919 Research Drive
Ada, Oklahoma 74821-1189 405-436-8660 FAX 405-436-8501

Sample	mg/L Cl^-	mg/L $SO_4^=$	mg/L $NO^-_2 + NO^-_3(N)$	mg/L NH_3
MW 1613-1	7.17	<.1	1.89	0.16
MW 1613-2	5.95	<.1	2.40	<.05
MW 1613-3	5.94	<.1	2.80	<.05
MW 1613-3A	5.92	<.1	3.22	<.05
MW 1613-4	5.86	<.1	0.51	1.32
MW 1613-4A	---ACIDIFIED---		2.73	<.05
MW 1613-5	5.52	3.56	<.05	1.74
MW 1613-5 Dup	5.39	3.53	<.05	1.75
MW 1613-6	4.76	<.1	3.45	<.05
MW 1613-7	3.58	<.1	0.90	<.05
MW 1613-8	3.89	3.09	<.05	0.91
MW 1613-9	5.70	<.1	0.18	1.16
MW 1613-9 Dup	5.67	<.1	-----	-----
MW 1613-9A	---ACIDIFIED---		2.30	<.05
MW 1613-10	4.31	2.36	1.09	<.05
MW 1613-11	4.04	<.1	<.05	1.33
MW 1613-12	4.68	51.6	0.21	0.47
MW 1613-13	4.07	3.27	0.54	<.05
MW 1613-13A	---ACIDIFIED---		2.25	<.05
MW 1613-14	2.78	1.27	1.02	<.05
MW 1613-14A	---ACIDIFIED---		1.84	<.05
MW 1613-15	4.04	17.6	1.51	<.05
MW 1613-15A	---ACIDIFIED---		1.55	<.05
MW 1613-16	3.05	2.49	1.34	<.05
MW 1613-16 Dup	3.04	2.71	-----	-----
MPA	.58	<.1	<.05	7.41
MPB	<.1	3.21	<.05	1.18
MPC	7.76	<.1	<.05	0.43
MPD	1.07	<.1	<.05	.20
MPE	.35	<.1	<.05	0.17
MPE Dup	.32	<.1	<.05	0.17
TMP-1	-------- NO SAMPLE RECEIVED --------			
TMP-2	---ACIDIFIED---		<.05	0.39
TMP-3	---ACIDIFIED---		0.41	<.05
TMP-4	---ACIDIFIED---		0.40	0.47
TMP-5	---ACIDIFIED---		<.05	0.37
TW-121	---ACIDIFIED---		<.05	6.35
MW-101 - TW101?	--- No Sample Received ---		1.20	0.78
MW-105	3.37	5.57	<.05	2.18
MW-106	.53	<.1	0.11	<.05
MW-107	2.97	4.00	0.26	<.05
MW-111	1.76	<.1	0.59	<.05
MW-112	.52	<.1	<.05	0.83

Sample	mg/L Cl^-	mg/L $SO_4^=$	mg/L $NO^-_2 + NO^-_3(N)$	mg/L NH_3
MW-112A	2.55	1.53	0.47	<.05
MW-112A Dup	2.53	1.41	-----	-----
MW-113	3.45	<.1	0.28	<.05
MW-114	5.87	2.75	<.05	<.05
MW-115	20.2	4.30	<.05	1.52
MW-115 Dup	-----	-----	<.05	1.52
MW-115A	3.92	<.1	0.99	<.05
MW-116	3.15	15.1	0.99	<.05
MW-116A	4.26	3.12	0.51	<.05
MW-117	4.23	20.4	<.05	0.26
MW-118	3.08	9.09	0.79	<.05
Unidentified #1	N/A	N/A	0.69	<.05
Unidentified #2	N/A	N/A	0.68	<.05
Unidentified #3	N/A	N/A	1.17	0.76
Blank	<.1	<.1	<.05	<.05
AQC	35.2	44.9	2.05	10.1
	35.0	44.2	-----	-----
AQC T.V.	34.8	44.0	2.10	10.0
Spike Rec.	100%	103%	99%	101%
	95%	102%	-----	-----

Acidified: An unpreserved sample was not received, prohibiting the analysis of chloride and sulfate.

Sample labels were unreadable on the "unidentified" samples.

Sample	Methane	Ethylene	Ethane
100ppm CH4	91.9	**	**
100ppm C2H4	**	86.6	**
100ppm C2H6	**	**	96.1
HPHe	**	**	**
Lab Blank	**	**	**
TMP-4	0.217	**	**
TMP-5	1.709	*	**
TW-101	0.153	**	**
MW-105	3.594	**	**
MW-106	0.058	**	**
MW-106	0.022	**	**
Lab Dup			
MW-107	0.006	**	**
MW-111	**	**	**
MW-112	6.047	**	**
MW-112A	**	**	**
MW-113	0.001	**	**
MW-113	0.001	**	**
Field Dup			
10ppm CH4	9.0	**	**
MW-114	1.135	**	**
MW-115	2.461	0.005	0.003
MW-115A	**	**	**
MW-116	**	**	**
MW-116A	**	**	**
MW-116A	**	**	**
Lab Dup			
MW-117	0.332	0.003	*
MW-118	0.001	**	**
TW-121	4.541	**	0.010
TW-121	4.164	*	0.012
Field Dup			
100ppm CH4	96.2	**	**
100ppm C2H4	**	86.7	**
100ppm C2H6	**	**	94.4
Lower Limit of Quantitation			
	0.001	0.003	0.002

Units for samples are mg/L.
Units for standards are parts per million.

** denotes None Detected.
* denotes Below Limit of Quantitation.

Sample	Methane	Ethylene	Ethane
100ppm CH4	111.5	**	**
100ppm C2H4	**	97.8	**
100ppm C2H6	**	**	91.9
HPHe	**	**	**
Lab Blank	**	**	**
MW1613-1	0.015	**	**
MW1613-2	**	**	**
MW1613-3	**	**	**
MW1613-3A	**	**	**
MW1613-4	0.072	**	**
MW1613-4	0.024	**	**
Lab Dup			
MW1613-4A	*	**	**
MW1613-5	0.102	**	**
MW1613-6	**	**	**
MW1613-7	0.052	**	**
MW1613-8	0.092	**	**
MW1613-8	0.092	**	**
Field Dup			
10ppm CH4	9.5	**	**
MW1613-9	0.009	**	**
MW1613-9A	*	**	**
MW1613-10	**	**	**
MW1613-11	0.138	**	**
MW1613-12	0.991	**	**
MW1613-12	0.708	**	**
Lab Dup			
MW1613-13	0.019	**	**
MW1613-13A	0.001	**	**
MW1613-14	*	**	**
MW1613-14A	**	**	**
MW1613-15	**	**	**
MW1613-15	**	**	**
Field Dup			
100ppm CH4	88.2	**	**
100ppm C2H4	**	99.0	**
100ppm C2H6	**	**	87.7
MW1613-15A	**	**	**
MW1613-16	0.481	**	**
MPA	6.952	**	**
MPB	3.378	**	**
MPC	0.070	*	0.005
MPC	0.077	*	0.002
Lab Dup			
MPD	1.631	**	**
MPE	0.029	**	**
TMP-1	0.001	**	**
TMP-2	0.341	*	**
TMP-3	0.186	*	**
TMP-3	0.195	*	**
Field Dup			
100ppm CH4	91.1	**	**
100ppm C2H4	**	88.3	**
100ppm C2H6	**	**	89.3
Lower Limit of Quantitation	0.001	0.003	0.002

Units for samples are mg/L.
Units for standards are parts per million.
** denotes None Detected.
* denotes Below Limit of Quantitation.

NATIONAL RISK MANAGEMENT RESEARCH LABORATORY
Subsurface Protection and Remediation Division
(Robert S. Kerr Environmental Research Center)
919 Kerr Research Drive
Post Office Box 1198 Ada, Oklahoma 74820
Fax: 405-436-8703

fax transmittal

to: Todd Herrington

fax: 303-831-8208

from: DON H. KAMPBELL
phone: TEL:405-436-8564
FAX:405-436-8703
E-Mail:kampbell.donald@epamail.epa.gov

date: 8/11/97

pages: 2 including cover sheet

NOTES: Floating product Analyses

SR #SF-3-266, Shaw AFB, Dr. D. Kampbell

Scan GC/MS of Floating Product Samples
Extracted Ion Quantitation by Standard Area Ratio

Units = ug/ml

Sample	Benzene	TCE	Toluene	Ethylbenzene	p-Xylene	m-Xylene	o-Xylene	1,3,5-TMB	1,2,4-TMB	1,2,3-TMB
MW1613-12	BLQ	ND	ND	2.45E+02	8.44E+01	3.91E+02	2.71E+02	4.88E+02	1.74E+03	6.63E+02
OU-4 MPC	2.64E+01	3.35E+03	3.17E+03	1.14E+03	8.53E+02	2.28E+03	1.69E+03	1.58E+03	4.29E+03	1.52E+03
OU-4 MPB	ND	ND	1422.4	8.47E+02	7.42E+02	1.74E+03	1.18E+03	1.41E+03	3.77E+03	1.27E+03

4,823

Analyst: D.A. Kovacs

BLQ < 20 ug/ml

Printed: 8/8/97

8-11-1997 6:36AM FROM APAB /BPAB 405 436 8703

Table I. Semi-Quantitative Report for Semi-volatiles found in the Methylene Chloride Extract of Sample MW-112 from Shaw AFB, Service Request SF-3-266.

	Concentration, ng/ml
Benzene	3.4
Toluene	172.8
Ethylbenzene	21.5
m+p-Xylene	814.8
o-Xylene	69.6
1-Methyl-3-ethylbenzene	86.7
1-Methyl-4-ethylbenzene	38.0
1,3,5-Trimethylbenzene	57.9
1-Methyl-2-ethylbenzene	30.3
1,2,4-Trimethylbenzene	178.3
1,2,3-Trimethylbenzene	64.6
Naphthalene	39.9

Ron Campbell
6/25/97

MANTECH

Ref: 97-MAB5/vg
May 27, 1997

Dr. Don Kampbell
National Risk Management Research Laboratory
Subsurface Protection & Remediation Division
U.S. Environmental Protection Agency
P.O. Box 1198
Ada, OK 74820

THRU: S.A. Vandegrift SV

Dear Don:

As per Service Request #SFTA-3-125, dissolved hydrogen analysis was performed onsite at Shaw AFB, S.C. using a RGA3 Reduction Gas Analyzer. The analysis began on May 14,1997 and was concluded on May 20, 1997. A six place (0.0 to 10.0PPM) external standard curve was used to quantitate the samples. The following data represents the concentration in the dissolved phase.

WELL	SHAW AFB, S.C. H_2 CONCENTRATION (nM)
MW 116	0.38
MW 116A	6.26
TW 101	1.13
MW 106	0.14
MW 105	0.35
MW 111	5.79
MW 115A	0.30
MW 115	0.10
MW 118	0.04
MW 117	0.10
MW 112	3.67
MW 112A	19.02

If you have any questions, please see me at your convenience.

Sincerely,
Mark Blankenship
Mark Blankenship

xc: R.L. Cosby
G.B. Smith
J.L. Seeley

ManTech Environmental Research Services Corporation
R.S. Kerr Environmental Research Laboratory, P.O. Box 1198, 919 Research Drive
Ada, Oklahoma 74821-1189 405-436-8660 FAX 405-436-8501

MANTECH

Ref: 97\LB35

June 3, 1997

Dr. Don Kampbell
National Risk Management Research Laboratory
Subsurface Protection and Remediation Division
U.S. Environmental Protection Agency
P.O. Box 1198
Ada, OK 74820

THRU: S.A. Vandegrift SV

Dear Don:

Please find attached the analytical results for Service Request SF-3-266, Shaw AFB, requesting the analysis of ground water samples to be analyzed by purge-and-trap/GC-PID:FID for Benzene, Toluene, Ethylbenzene, p-, m-, & o-Xylene, 1,3,5-, 1,2,4-, & 1,2,3-Trimethylbenzene, and Total Fuel Carbon. We obtained the 55 aqueous samples, in duplicate, in capped, 40 mL VOA autosampler vials May 22, 1997 and they were analyzed May 29-June 2, 1997. The samples were acquired and processed using the Millennium data system. A 6 place (1-1000 ppb) external calibration curve was used to quantitate sample concentration for all the compounds of interest.

RSKSOP-122, "Analysis of Volatile Aromatic Hydrocarbons with Separation of Xylene Isomers by Purge & Trap Gas Chromatography" was used for these analyses. Autosampling was performed using a Dynatech Precision autosampler system in line with a Tekmar LSC 2000 concentrator.

Sincerely,

Lisa R. Black

Lisa R. Black

xc: R.L. Cosby
G.B. Smith
J.T. Wilson
J.L. Seeley JB

David Kovacs

ManTech Environmental Research Services Corporation

R.S. Kerr Environmental Research Laboratory, P.O. Box 1198, 919 Research Drive
Ada, Oklahoma 74821-1189 405-436-8660 FAX 405-436-8501

Printed 6/3/97 SF-3-266

Shaw AFB GW Analyses Presented to Dr. Kampbell

Units = ng/mL Analyst: L. Black

SampleName	BENZENE	TOLUENE	ETHYLBENZENE	p-XYLENE	m-XYLENE	o-XYLENE	1,3,5-TMB	1,2,4-TMB	1,2,3-TMB	Fuel Carbon
100 PPB	95.9	103	109	109	110	107	116	113	110	N/A
QC, OBSERVED, PPB	48.8	50.6	50.6	54.7	53.0	53.5	57.2	56.7	49.3	N/A
QC, TRUE VALUE, PPB	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	N/A
MW1613-1	207	BLQ	28.0	17.1	BLQ	15.5	15.9	69.5	27.5	924
MW1613-1 Duplicate	201	BLQ	26.1	15.8	BLQ	14.4	14.7	65.9	25.9	881
MW1613-2	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MW1613-3	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MW1613-3A	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MW1613-4	1330	903	444	390	543	444	151	441	175	6470
MW1613-4A	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MW1613-5	1632	984	320	332	551	427	92.9	295	121	5810
MW1613-6	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MW1613-7	7.8	26.4	22.4	23.5	48.2	25.2	33.5	101.7	47.5	2330
10 PPB	9.4	10.1	10.5	10.3	10.5	10.1	10.6	10.4	10.2	N/A
MW1613-8	975	570	87.7	96.4	233	151	21.6	75.1	45.9	3050
MW1613-9	594	551	189	217	331	350	100	222	127	3930
MW1613-9 Duplicate	702	659	216	243	374	412	112	253	143	4240
MW1613-9A	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MW1613-10	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MW1613-11	1202	1042	364	309	744	486	99.0	300	162	6310
MW1613-12	58.3	8.5	80.2	60.7	136	78.4	45.6	178	99.5	1330
MW1613-12rinse	BLQ	3.3	ND	ND	BLQ	ND	ND	1.0	BLQ	44.3
MW1613-13	2.5	BLQ	BLQ	BLQ	1.0	BLQ	1.8	1.3	1.5	117
MW1613-13A	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MW1613-14	BLQ	ND	ND	ND	BLQ	ND	ND	ND	ND	BLQ
500 PPB	465	457	452	451	450	454	455	454	460	N/A
MW1613-14A	ND	ND	ND	ND	BLQ	BLQ	ND	ND	ND	BLQ
MW1613-15	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MW1613-15A	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MW1613-16	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MW1613-16 Duplicate	ND	ND	ND	ND	BLQ	ND	ND	ND	ND	BLQ
MPA	14.5	943	403	388	922	624	152	321	206	5540
MPB	7.1	917	224	228	548	325	118	326	144	4130
MPC	81.7	1685	242	254	638	387	118	328	148	4730
MPD	19.3	159	142	142	232	122	40.4	204	44.9	1720
MPE	ND	ND	ND	BLQ	BLQ	ND	ND	ND	ND	BLQ

ND = None Detected; BLQ = Below Limit of Quantitation, 1 ppb; N/A = Not Analyzed

Printed 6/3/97 SF-3-266

Shaw AFB GW Analyses Presented to Dr. Kampbell

Units = ng/mL Analyst: L. Black

SampleName	BENZENE	TOLUENE	ETHYLBENZENE	p-XYLENE	m-XYLENE	o-XYLENE	1,3,5-TMB	1,2,4-TMB	1,2,3-TMB	Fuel Carbon
QC, OBSERVED, PPB	46.3	47.7	46.8	54.0	52.5	49.6	51.9	52.0	45.8	N/A
QC, TRUE VALUE, PPB	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	N/A
TMP-1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
TMP-2	12.5	2.3	2.4	2.8	0.9	1.0	0.9	4.2	9.7	127
TMP-3	12.4	ND	ND	ND	ND	2.2	ND	ND	4.5	60.4
TMP-4	10.1	BLQ	8.4	8.5	ND	ND	BLQ	13.2	BLQ	207
TMP-4 Duplicate	10.7	BLQ	8.9	8.3	ND	ND	BLQ	13.8	0.9	197
TMP-5	28.2	9.9	77.2	70.2	49.1	9.0	19.0	72.3	27.7	529
SWS-1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
SWS-2	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
SWS-2 Duplicate	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
SWS-3	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
SWS-4	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
SWS-5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
GC LAB BLANK, PPB	ND	ND	ND	ND	ND	ND	ND	ND	ND	N/A
1 PPB	0.9	0.8	0.9	0.9	1.0	0.8	0.8	0.8	0.8	N/A
TW-120	ND	2.1	ND	ND	ND	ND	ND	ND	ND	1.8
TW-121	5.3	1.2	1.0	1.2	0.9	1.9	ND	0.9	1.2	16.1
TW-101	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MW-105	70.7	7.1	37.9	92.5	65.7	66.7	3.5	137	52.7	930
MW-106	BLQ	BLQ	2.6	2.1	BLQ	BLQ	ND	2.8	ND	14.0
MW-107	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MW 107 Duplicate	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MW-111	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MW-112	229	438	495	501	1037	199	177	521	193	5080
MW-112A	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MW-113	ND	ND	BLQ	BLQ	0.9	ND	ND	ND	ND	BLQ
100 PPB	87.8	93.1	98.7	104	105	96.5	104	101	99.9	N/A
MW-114	6.3	12.2	56.8	57.9	103	59.0	14.3	74.9	20.3	623
MW-115	157	393	113	135	240	213	26.0	191	90.7	2350
MW-115A	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MW-116	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MW-116A	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MW-117	30.0	89.5	72.8	83.5	190	123	13.4	90.5	41.1	1290
MW 117 Duplicate	30.7	93.7	74.5	79.6	181	127	14.0	92.3	42.7	1280
MW-118	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
500 PPB	499	503	506	487	487	509	518	514	516	N/A

ND = None Detected; BLQ = Below Limit of Quantitation, 1 ppb; N/A = Not Analyzed

MANTECH

Ref: 97JAD31

June 3, 1997

Dr. Don Kampbell
National Risk Management Research Laboratory
Subsurface Protection and Remediation Division
U.S. Environmental Protection Agency
P.O. Box 1198
Ada, OK 74820

THRU: S.A. Vandegrift SV

Dear Don:

As requested in Service Request # SF-3-266, headspace GC/MS analysis of 55 Shaw AFB water samples for chlorinated volatile organics was completed. The samples were received on May 22, 1997 and analyzed on May 23-24 & 28-29, 1997. RSKSOP-148 (Determination of Volatile Organic Compounds in Water by Automated Headspace Gas Chromatography/Mass Spectrometry (Saturn II Ion Trap Detector) was used for this analysis.

An internal standard calibration method was established for the 15 compounds. The standard curves were prepared from 1.0 to 4000 ppb. The lower calibration limits were 1.0 ppb.

A dilution corrected quantitation report for the samples, lab duplicates, field duplicates, QC standards and lab blanks is presented in tables 1-3.

If you should have any questions, please feel free to contact me.

Sincerely,

John Allen Daniel

xc: R.L. Cosby
G.B. Smith
D.D. Fine
J.L. Seeley
J.T. Wilson JB

ManTech Environmental Research Services Corporation

R.S. Kerr Environmental Research Laboratory, P.O. Box 1198, 919 Research Drive
Ada, Oklahoma 74821-1189 405-436-8660 FAX 405-436-8501

Table 1. Quantitation Report for S.R. # SF-3-266 from Shaw AFB.

Concentration = ppb

Compound	MW1613 1	MW1613 2	1613 3	1613 3A	1613 4	MW1613 4A	MW1613 5	MW1613 6	MW1613 7	MW1613 8
VINYL CHLORIDE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,1-DICHLOROETHENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
T-1,2-DICHLOROETHENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,1-DICHLOROETHANE	ND	ND	ND	ND	ND	ND	ND	ND	ND	---
C-1,2-DICHLOROETHENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
CHLOROFORM	ND	ND	ND	ND	1.9	ND	1.4	ND	---	1.0
1,1,1-TRICHLOROETHANE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
CARBON TETRACHLORIDE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,2-DICHLOROETHANE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
TRICHLOROETHENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
TETRACHLOROETHENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
CHLOROBENZENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,3-DICHLOROBENZENE	1.2	---	---	---	ND	---	ND	---	ND	ND
1,4-DICHLOROBENZENE	---	---	---	---	---	ND	---	ND	ND	ND
1,2-DICHLOROBENZENE	---	---	---	---	ND	ND	ND	---	ND	ND

Compound	MW1613 8 Lab Dup	MW1613 8 Field Dup	MW1613 9	MW1613 9A	MW1613 10	MW1613 11	1613 12	1613 12 RINSE	MW1613 13	MW1613 13A
VINYL CHLORIDE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,1-DICHLOROETHENE	ND	ND	ND	ND	ND	ND	ND	ND	---	---
T-1,2-DICHLOROETHENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,1-DICHLOROETHANE	---	ND	---	ND	ND	ND	---	ND	ND	ND
C-1,2-DICHLOROETHENE	ND	ND	ND	ND	ND	ND	ND	ND	---	ND
CHLOROFORM	1.0	1.0	---	ND	ND	1.7	ND	1.3	ND	ND
1,1,1-TRICHLOROETHANE	ND	ND	ND	ND	ND	ND	ND	---	ND	ND
CARBON TETRACHLORIDE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,2-DICHLOROETHANE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
TRICHLOROETHENE	ND	ND	ND	ND	ND	ND	ND	---	---	ND
TETRACHLOROETHENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
CHLOROBENZENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,3-DICHLOROBENZENE	ND	ND	ND	---	---	ND	ND	ND	ND	ND
1,4-DICHLOROBENZENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,2-DICHLOROBENZENE	ND	ND	ND	---	---	ND	ND	ND	ND	ND

ND = None Detected --- = Below Calibration Limit(1.0 ppb) Dup = Duplicate

Table 2. Quantitation Report for S.R. # SF-3-266 from Shaw AFB.

Concentration = ppb

Compound	MW1613 14	MW1613 14A	MW1613 14A Lab Dup	MW1613 15	MW1613 15A	MW1613 16	MPA	MPB	MPC	MPC Field Dup 1/10 Dil
VINYL CHLORIDE	ND	ND	ND	ND	ND	ND	ND	ND	30.4	31.0
1,1-DICHLOROETHENE	ND	ND	ND	ND	ND	ND	4.3	4.7	748	727
T-1,2-DICHLOROETHENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,1-DICHLOROETHANE	ND	ND	ND	ND	ND	ND	30.8	15.4	1060	1030
C-1,2-DICHLOROETHENE	ND	ND	ND	ND	ND	ND	3.5	10.6	*****	4590
CHLOROFORM	ND	ND	ND	ND	ND	ND	2.0	---	1.2	ND
1,1,1-TRICHLOROETHANE	ND	ND	ND	ND	ND	ND	8.4	411	*****	23000
CARBON TETRACHLORIDE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,2-DICHLOROETHANE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
TRICHLOROETHENE	ND	ND	ND	ND	ND	ND	---	1.3	718	793
TETRACHLOROETHENE	ND	ND	ND	ND	ND	ND	ND	---	90.7	100
CHLOROBENZENE	ND	ND	ND	ND	ND	ND	ND	---	9.2	---
1,3-DICHLOROBENZENE	ND	ND	ND	ND	ND	ND	ND	1.1	14.1	11.0
1,4-DICHLOROBENZENE	ND	ND	ND	ND	ND	ND	ND	16.8	68.2	55.0
1,2-DICHLOROBENZENE	ND	ND	ND	ND	ND	ND	ND	13.5	117	95.0

	MPD	MPE	TMP-1 FT-1	TMP-2 OU4	TMP-2 OU4 Lab Dup	TMP-3 FT1/OU4	TMP-4 FT1	TMP-5 FT1	SWS-1	SWS-2
VINYL CHLORIDE	ND	ND	ND	22.8	22.4	59.6	7.7	116	ND	ND
1,1-DICHLOROETHENE	1.7	ND	ND	116	113	40.2	3.5	1.8	ND	ND
T-1,2-DICHLOROETHENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,1-DICHLOROETHANE	53.3	1.4	ND	1070	1030	1153	64.9	3.5	ND	ND
C-1,2-DICHLOROETHENE	155	4.9	ND	339	318	150	169	42.5	ND	---
CHLOROFORM	---	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,1,1-TRICHLOROETHANE	1.3	---	ND	78.6	116	60.5	---	ND	ND	ND
CARBON TETRACHLORIDE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,2-DICHLOROETHANE	ND	ND	ND	ND	ND	2.1	ND	ND	ND	ND
TRICHLOROETHENE	77.0	ND	ND	1.2	1.1	3.9	---	ND	ND	ND
TETRACHLOROETHENE	ND	ND	ND	---	---	1.0	ND	ND	ND	ND
CHLOROBENZENE	ND	ND	ND	---	---	---	ND	ND	ND	ND
1,3-DICHLOROBENZENE	ND	ND	ND	1.8	1.6	ND	---	ND	ND	ND
1,4-DICHLOROBENZENE	ND	ND	ND	5.6	5.3	3.3	2.2	ND	ND	ND
1,2-DICHLOROBENZENE	ND	ND	ND	10.5	9.8	6.3	2.5	ND	ND	ND

ND = None Detected --- = Below Calibration Limit(1.0 ppb) Dil = Dilution ***** = Above Calibration Limit(4000 ppb)

Table 3. Quantitation Report for S.R. # SF-3-266 from Shaw AFB.

Concentration = ppb

Compound	SWS-3	SWS-4	SWS-5	TM-120 FT1/OU4 1/10 Dil	TM-120 FT1/OU4 Field Dup	TM-121 FT1	TM-121 FT1 Lab Dup	TMP-101	MW 105	MW-106
VINYL CHLORIDE	ND	ND	ND	ND	ND	15.3	16.7	ND	1.2	ND
1,1-DICHLOROETHENE	---	ND	ND	ND	ND	7.3	7.7	ND	---	---
T-1,2-DICHLOROETHENE	ND	ND	ND	ND	ND	2.1	2.2	ND	ND	ND
1,1-DICHLOROETHANE	1.0	---	ND	ND	1.7	1.5	1.6	ND	---	3.0
C-1,2-DICHLOROETHENE	2.3	---	ND	ND	---	30.7	30.8	ND	201	5.9
CHLOROFORM	ND	ND	ND	ND	ND	ND	ND	ND	47.9	ND
1,1,1-TRICHLOROETHANE	---	ND	ND	ND	ND	ND	ND	ND	ND	ND
CARBON TETRACHLORIDE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,2-DICHLOROETHANE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
TRICHLOROETHENE	ND	ND	ND	ND	ND	ND	ND	ND	31.3	ND
TETRACHLOROETHENE	ND	ND	ND	ND	ND	ND	ND	ND	---	ND
CHLOROBENZENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,3-DICHLOROBENZENE	ND	ND	ND	ND	ND	---	---	ND	ND	ND
1,4-DICHLOROBENZENE	ND	ND	ND	ND	ND	---	---	ND	ND	ND
1,2-DICHLOROBENZENE	ND	ND	ND	ND	ND	1.7	1.8	ND	ND	ND

	MW-107	MW-111	MW-112	MW-112A	MW-113	MW-114	MW-115	MW-115 Lab Dup	MW-115 Field Dup 1/10 Dil	MW-115A
VINYL CHLORIDE	ND	ND	ND	ND	ND	ND	416	438	474	ND
1,1-DICHLOROETHENE	ND	ND	2.2	ND	ND	2.1	368	373	402	2.1
T-1,2-DICHLOROETHENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,1-DICHLOROETHANE	1.1	ND	64.8	ND	---	58.8	*****	*****	8700	---
C-1,2-DICHLOROETHENE	1.5	ND	22.0	ND	1.2	87.1	1620	1600	1740	ND
CHLOROFORM	ND	ND	2.3	ND	ND	---	---	---	---	ND
1,1,1-TRICHLOROETHANE	ND	ND	---	ND	ND	ND	2030	2460	2050	ND
CARBON TETRACHLORIDE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,2-DICHLOROETHANE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
TRICHLOROETHENE	ND	---	ND	ND	ND	ND	10.2	10.5	10.0	---
TETRACHLOROETHENE	ND	ND	ND	ND	ND	ND	4.8	4.9	ND	ND
CHLOROBENZENE	ND	ND	ND	ND	ND	ND	4.9	5.1	---	ND
1,3-DICHLOROBENZENE	ND	ND	ND	ND	ND	ND	11.6	12.2	11.0	ND
1,4-DICHLOROBENZENE	ND	ND	ND	ND	ND	ND	46.4	47.0	44.0	ND
1,2-DICHLOROBENZENE	ND	ND	ND	ND	ND	ND	88.9	93.7	83.0	ND

ND = None Detected --- = Below Calibration Limit(1.0 ppb) Dup = Duplicate Dil = Dilution

Table 4. Quantitation Report for S.R. # SF-3-266 from Shaw AFB.

Concentration = ppb

Compound	MW-116	MW-116A	MW-117	MW-117 Field Dup 1/10 Dil	MW-118	MW-118 Lab Dup	QC0523A 20 ppb	QC0523B 200 ppb	QC0523C 20 ppb	QC0523D 200 ppb
VINYL CHLORIDE	ND	ND	84.6	94.0	ND	ND	18.7	170	17.6	175
1,1-DICHLOROETHENE	ND	ND	148	159	ND	ND	23.3	223	22.1	223
T-1,2-DICHLOROETHENE	ND	ND	ND	ND	ND	ND	20.7	210	20.3	206
1,1-DICHLOROETHANE	ND	ND	481	509	ND	ND	21.0	206	21.4	210
C-1,2-DICHLOROETHENE	ND	ND	457	508	ND	ND	20.2	205	20.3	210
CHLOROFORM	ND	ND	---	ND	ND	ND	20.4	207	20.4	206
1,1,1-TRICHLOROETHANE	ND	ND	*****	4690	---	---	21.6	207	20.6	214
CARBON TETRACHLORIDE	ND	ND	ND	ND	ND	ND	20.8	204	19.5	207
1,2-DICHLOROETHANE	ND	ND	ND	ND	ND	ND	21.1	213	22.0	212
TRICHLOROETHENE	ND	ND	203	217	ND	ND	18.1	189	18.1	191
TETRACHLOROETHENE	ND	ND	24.1	25.0	ND	ND	21.5	205	20.5	204
CHLOROBENZENE	ND	ND	2.1	---	ND	ND	21.1	213	21.4	222
1,3-DICHLOROBENZENE	ND	ND	3.4	---	ND	ND	23.0	219	20.4	216
1,4-DICHLOROBENZENE	ND	ND	14.9	14.0	ND	ND	22.1	225	21.7	219
1,2-DICHLOROBENZENE	ND	ND	25.1	23.0	ND	ND	22.7	225	21.8	222

	QC0523E 20 ppb	QC0523F 200 ppb	QC0523G 20 ppb	QC0523H 200 ppb	QC0528I 200 ppb	QC0528J 20 ppb	QC0528K 200 ppb	QC0528L 20 ppb	QC0528M 200 ppb	BL0523A BLK
VINYL CHLORIDE	18.0	174	18.4	20.2	181	18.2	180	18.5	179	ND
1,1-DICHLOROETHENE	21.9	228	22.6	25.2	230	23.0	230	23.2	230	ND
T-1,2-DICHLOROETHENE	20.2	210	20.5	21.8	210	21.2	201	20.4	208	ND
1,1-DICHLOROETHANE	21.5	214	21.0	22.0	216	21.2	212	21.6	209	ND
C-1,2-DICHLOROETHENE	20.6	208	21.1	20.9	211	21.5	204	20.1	199	ND
CHLOROFORM	20.7	203	21.0	20.4	206	21.3	201	20.5	202	ND
1,1,1-TRICHLOROETHANE	20.9	214	20.5	22.7	218	21.8	215	20.8	218	ND
CARBON TETRACHLORIDE	20.4	209	20.3	22.7	209	21.2	211	20.7	213	ND
1,2-DICHLOROETHANE	22.2	210	21.1	22.3	209	22.5	203	20.8	206	ND
TRICHLOROETHENE	17.6	189	18.0	18.8	192	18.3	186	17.8	190	ND
TETRACHLOROETHENE	19.4	208	19.8	23.3	210	21.8	209	20.9	207	ND
CHLOROBENZENE	21.5	216	20.3	21.0	218	22.8	213	20.7	208	ND
1,3-DICHLOROBENZENE	18.9	213	18.6	20.2	217	20.6	209	19.5	210	ND
1,4-DICHLOROBENZENE	20.8	218	19.6	20.6	221	20.9	219	21.0	218	ND
1,2-DICHLOROBENZENE	20.2	221	19.7	20.1	226	21.5	215	20.6	220	ND

ND = None Detected --- = Below Calibration Limit(1.0 ppb) Dup = Duplicate QC = Quality Control Std. BL = Blank ***** = Above Calibration Limit(4000 ppb)

MANTECH

Ref: 97-SH33

June 2, 1997

Dr. Don Kampbell
National Risk Management Research Laboratory
Subsurface Protection & Remediation Division
U.S. Environmental Protection Agency
P.O. Box 1198
Ada, OK 74820

THRU: S.A. Vandegrift SV

Dear Don:

Attached are TOC results for 46 Shaw liquids submitted May 28, 1997 under Service Request #SF-3-266. Sample analysis was begun May 29, 1997 and completed June 2, 1997 using RSKSOP-102.

Blanks, duplicates, and AQC samples were analyzed along with your samples, as appropriate, for quality control. If you have any questions concerning this data, please feel free to ask me.

Sincerely,

Sharon Hightower

Sharon Hightower

xc: R.L. Cosby
G.B. Smith
J.L. Seeley JS

ManTech Environmental Research Services Corporation

R.S. Kerr Environmental Research Laboratory, P.O. Box 1198, 919 Research Drive
Ada, Oklahoma 74821-1189 405-436-8660 FAX 405-436-8501

KAMPBELL SHAW LIQUIDS SF-3-266

SAMPLE	MG/L TOC
TMP-1	1.74
TMP-2	2.85
TMP-3	1.76
TMP-4	2.71
MW105	22.2
MW106	1.93
MW107	1.66
MW111	1.37
MW112	22.0
DUP	22.0
MW112A	.884
MW113	1.43
MW114	2.78
MW115	8.59
MW115A	1.06
MW116	1.05
MW117	3.72
MW118	5.71
MW1613-1	1.75
MW1613-2	1.52
MW1613-3	.857
MW1613-3A	.814
MW1613-4	2.59
MW1613-4A	2.77
MW1613-5	50.9
DUP	51.3
MW1613-6	3.82
MW1613-7	1.24
MW1613-8	1.88
MW1613-9	1.96
MW1613-9A	1.27
MW1613-10	.740
MW1613-11	2.91
MW1613-12	4.65
MW1613-13	1.30
MW1613-13A	1.75
DUP	1.62
MW1613-14	.953
MW1613-14A	15.7
MW1613-15	.932
MW1613-15A	2.07
MW1613-16	1.24
MPA	144
MPB	5.27
DUP	5.77
MPC	7.75

SAMPLE	MG/L TOC
MPE	1.51
116A	.909
TW101	2.39
TW121	25.5
WSO38	4.75

WSO38 std t.v.=4.92

MANTECH

May 30, 1997

Dr. Don Kampbell
National Risk Management Research Laboratory
Subsurface Protection & Remediation Division
U.S. Environmental Protection Agency
P.O. Box 1198
Ada, OK 74820

THRU: S.A. Vandegrift SV

Dear Don:

Attached are TOC results for 5 Shaw soils submitted May 22, 1997 under Service Request #SF-3-266. Sample analysis was begun May 27, 1997 and completed May 30, 1997 using RSKSOP-102 and RSKSOP-120.

Blanks, duplicates, and AQC samples were analyzed along with your samples, as appropriate, for quality control. If you have any questions concerning this data, please feel free to ask me.

Sincerely,

Sharon Hightower

Sharon Hightower

xc: R.L. Cosby
G.B. Smith
J.L. Seeley JS

ManTech Environmental Research Services Corporation

R.S. Kerr Environmental Research Laboratory, P.O. Box 1198, 919 Research Drive
Ada, Oklahoma 74821-1189 405-436-8660 FAX 405-436-8501

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82 .55.cc

KAMPBELL SHAW SOILS SF-3-266

SAMPLE	SOIL FILTRATE % O.C.	SOLIDS % TOC	TOTAL SOIL % TOC	MEAN %TOC	STD DEV
SED 1,1-1	.028	.522	.550	.389	.154
1-2	.028	.346	.374		
1-3	.031	.212	.243		
SED 2,1-1	.058	.956	1.01	1.09	.085
1-2	.066	1.11	1.18		
1-3	.070	1.02	1.09		
SED 3,1-1	.108	4.88	4.99	4.84	.240
1-2	.105	4.45	4.56		
1-3	.115	4.86	4.96		
SED 4,1-1	.028	.186	.214	.219	.010
1-2	.030	.200	.230		
1-3	.027	.185	.212		
SED 5,1-1	.043	10.70	10.74	10.89	.516
1-2	.040	10.42	10.46		
1-3	.047	11.41	11.46		
LECO STD		.934			
WSO38	4.60				

Leco soil std t.v.=.90+/-.04
WSO38 std t.v.=4.92

MANTECH

Ref: 97-BS3/vg
97-MAB6/vg

May 29, 1997

Dr. Don Kampbell
National Risk Management Research Laboratory
Subsurface Protection and Remediation Division
U.S. Environmental Protection Agency
P.O. Box 1198
Ada, OK 74820

THRU: Steve Vandegrift SV

Dear Don:

Please find attached the analytical results for Service Request #SF-3-124 requesting the analysis of 49 field samples for CO_2, Ferrous Iron, Total Alkalinity, Hydrogen Sulfide, Phenols, and Manganese. Samples were analyzed May 14, 15, 16, 17, 19, and 20, 1997.

Please note that samples with greater than 5.0 mg/l Ferrous Iron may have interfered with the Hach carbon dioxide color test. If you have any questions concerning these results, please feel free to contact us.

Sincerely,

Brad Scroggins

Mark Blankenship

xc: R.L. Cosby
G.B. Smith
J.L. Seeley

ManTech Environmental Research Services Corporation

R.S. Kerr Environmental Research Laboratory, P.O. Box 1198, 919 Research Drive
Ada, Oklahoma 74821-1189 405-436-8660 FAX 405-436-8501

Sample	CO_2 (mg/L)	Fe^{2+} mg/L	Total Alkalinity ($CaCO_3$) mg/L	H_2S mg/L	Phenols mg/L
MW 116μ	28	ND	10	<0.1	<0.1
MW 116	18	0.04	20	<0.1	<0.1
TW 101	50	0.84	50	<0.1	<0.1
MW 107	28	1.05	20	<0.1	<0.1
MW 106	32	3.00	20	0.1	<0.1
MW 105	88	3.08	20	<0.1	<0.1
MW 111	26	ND	10	<0.1	<0.1
MW 115	84	5.90	70	0.5	<0.1
MW 115A	22	0.08	10	<0.1	<0.1
2.0 ppm Std. Fe^{2+}	-----	1.94	----	-----	-----
MW 118	34	ND	30	<0.1	<0.1
MW 114	36	2.15	20	0.5	<0.1
MW 117	44	0.03	10	<0.1	<0.1
MW 112	120	7.00	60	0.5	<0.1
MW 112A	20	0.01	10	<0.1	<0.1
MW 113	22	0.13	10	<0.1	<0.1
MPC	70	4.00	30	0.3	<0.1
MPA	100	4.00	250	0.2	0.94
MW 1613-6	30	0.12	10	0.1	<0.1
MPB	28	3.00	30	2.0	<0.1
MW 1613-10	35	0.12	10	<0.1	<0.1
TMP-5	50	4.00	30	<0.1	<0.1
TMP-4	50	4.00	20	0.1	<0.1
MW 1613-2	35	0.12	10	<0.1	<0.1
MPE	50	7.00	30	<0.1	<0.1
MW 1613-3	30	0.03	20	<0.1	<0.1
TMP-3	40	0.18	10	<0.1	<0.1
TW-121	40	4.00	130	<0.1	<0.1
MW 1613-15	30	0.32	10	<0.1	<0.1
TMP-1	30	0.20	10	<0.1	<0.1
MW 1613-12	115	15.00	50	<0.1	<0.1
TMP-2	80	8.20	20	0.3	<0.1
MW 1613-8	80	6.90	90	<0.1	<0.1
MW 1613-9	40	21.00	70	0.1	<0.1
MW 1613-1	55	14.00	20	<0.1	<0.1
MW 1613-9A	35	ND	10	<0.1	<0.1
MW 1613-11	75	45.00	100	<0.1	<0.1
MW 1613-5A	30	0.13	10	<0.1	<0.1
MW 1613-5	70	4.00	100	<0.1	<0.1
MW 1613-7	55	9.00	20	<0.1	<0.1
MW 1613-3A	30	2.01	20	0.5	<0.1

Sample	CO_2 (mg/L)	Fe^{2+} mg/L	Total Alkalinity ($CaCO_3$) mg/L	H_2S mg/L	Phenols mg/L
MW 1613-4	50	8.40	100	<0.1	<0.1
MW 1613-13	70	0.09	10	<0.1	<0.1
MW 1613-13A	30	0.05	10	<0.1	<0.1
MW 1613-14	55	0.03	10	<0.1	<0.1
MW 1613-14A	10	0.09	110	0.3	<0.1
MW 1613-16	35	0.01	30	<0.1	<0.1
MW 1613-4A	30	0.03	20	0.3	<0.1

MANTECH

Ref: 97-MW42/vg
97-LP53/vg

May 29, 1997

Dr. Don Kampbell
National Risk Management Research Laboratory
Subsurface Protection & Remediation Division
U.S. Environmental Protection Agency
P.O. Box 1198
Ada, OK 74820

THRU: S.A. Vandegrift SV

Dear Don:

Attached are the results of 50 Shaw AFB samples submitted to MERSC as part of Service Request #SF-3-266. The samples were received May 22 and analyzed May 23 and 27, 1997. The methods used for analysis were EPA Methods 353.1 for NO_2 and NO_3 and 350.1 for NH_3, and Waters capillary electrophoresis Method N-601 for Cl and SO_4. Quality assurance measures performed on this set of samples included spikes, duplicates, known AQC samples and blanks.

If you have any questions concerning these results, please feel free to contact us.

Sincerely,

Mark White

Lynda Pennington

xc: R.L. Cosby
G.B. Smith
J.L. Seeley SV for

ManTech Environmental Research Services Corporation

R.S. Kerr Environmental Research Laboratory, P.O. Box 1198, 919 Research Drive
Ada, Oklahoma 74821-1189 405-436-8660 FAX 405-436-8501

Sample	mg/L Cl^-	mg/L $SO_4^{=}$	mg/L $NO^-_2 + NO^-_3(N)$	mg/L NH_3
MW 1613-1	7.17	<.1	1.89	0.16
MW 1613-2	5.95	<.1	2.40	<.05
MW 1613-3	5.94	<.1	2.80	<.05
MW 1613-3A	5.92	<.1	3.22	<.05
MW 1613-4	5.86	<.1	0.51	1.32
MW 1613-4A	---ACIDIFIED---		2.73	<.05
MW 1613-5	5.52	3.56	<.05	1.74
MW 1613-5 Dup	5.39	3.53	<.05	1.75
MW 1613-6	4.76	<.1	3.45	<.05
MW 1613-7	3.58	<.1	0.90	<.05
MW 1613-8	3.89	3.09	<.05	0.91
MW 1613-9	5.70	<.1	0.18	1.16
MW 1613-9 Dup	5.67	<.1	-----	-----
MW 1613-9A	---ACIDIFIED---		2.30	<.05
MW 1613-10	4.31	2.36	1.09	<.05
MW 1613-11	4.04	<.1	<.05	1.33
MW 1613-12	4.68	51.6	0.21	0.47
MW 1613-13	4.07	3.27	0.54	<.05
MW 1613-13A	---ACIDIFIED---		2.25	<.05
MW 1613-14	2.78	1.27	1.02	<.05
MW 1613-14A	---ACIDIFIED---		1.84	<.05
MW 1613-15	4.04	17.6	1.51	<.05
MW 1613-15A	---ACIDIFIED---		1.55	<.05
MW 1613-16	3.05	2.49	1.34	<.05
MW 1613-16 Dup	3.04	2.71	-----	-----
MPA	.58	<.1	<.05	7.41
MPB	<.1	3.21	<.05	1.18
MPC	7.76	<.1	<.05	0.43
MPD	1.07	<.1	<.05	.20
MPE	.35	<.1	<.05	0.17
MPE Dup	.32	<.1	<.05	0.17
TMP-1	- - - - - - - - NO SAMPLE RECEIVED - - - - - - - -			
TMP-2	---ACIDIFIED---		<.05	0.39
TMP-3	---ACIDIFIED---		0.41	<.05
TMP-4	---ACIDIFIED---		0.40	0.47
TMP-5	---ACIDIFIED---		<.05	0.37
TW-121	---ACIDIFIED---		<.05	6.35
MW-101	--- No Sample Received ---		1.20	0.78
MW-105	3.37	5.57	<.05	2.18
MW-106	.53	<.1	0.11	<.05
MW-107	2.97	4.00	0.26	<.05
MW-111	1.76	<.1	0.59	<.05
MW-112	.52	<.1	<.05	0.83

Sample	mg/L Cl^-	mg/L $SO_4^=$	mg/L $NO^-_2 + NO^-_3(N)$	mg/L NH_3
MW-112A	2.55	1.53	0.47	<.05
MW-112A Dup	2.53	1.41	-----	-----
MW-113	3.45	<.1	0.28	<.05
MW-114	5.87	2.75	<.05	<.05
MW-115	20.2	4.30	<.05	1.52
MW-115 Dup	-----	-----	<.05	1.52
MW-115A	3.92	<.1	0.99	<.05
MW-116	3.15	15.1	0.99	<.05
MW-116A	4.26	3.12	0.51	<.05
MW-117	4.23	20.4	<.05	0.26
MW-118	3.08	9.09	0.79	<.05
Unidentified #1	N/A	N/A	0.69	<.05
Unidentified #2	N/A	N/A	0.68	<.05
Unidentified #3	N/A	N/A	1.17	0.76
Blank	<.1	<.1	<.05	<.05
AQC	35.2	44.9	2.05	10.1
	35.0	44.2	-----	-----
AQC T.V.	34.8	44.0	2.10	10.0
Spike Rec.	100%	103%	99%	101%
	95%	102%	-----	-----

Acidified: An unpreserved sample was not received, prohibiting the analysis of chloride and sulfate.

Sample labels were unreadable on the "unidentified" samples.

Sample	Methane	Ethylene	Ethane
100ppm CH4	91.9	**	**
100ppm C2H4	**	86.6	**
100ppm C2H6	**	**	96.1
HPHe	**	**	**
Lab Blank	**	**	**
TMP-4	0.217	**	**
TMP-5	1.709	*	**
TW-101	0.153	**	**
MW-105	3.594	**	**
MW-106	0.058	**	**
MW-106	0.022	**	**
Lab Dup			
MW-107	0.006	**	**
MW-111	**	**	**
MW-112	6.047	**	**
MW-112A	**	**	**
MW-113	0.001	**	**
MW-113	0.001	**	**
Field Dup			
10ppm CH4	9.0	**	**
MW-114	1.135	**	**
MW-115	2.461	0.005	0.003
MW-115A	**	**	**
MW-116	**	**	**
MW-116A	**	**	**
MW-116A	**	**	**
Lab Dup			
MW-117	0.332	0.003	*
MW-118	0.001	**	**
TW-121	4.541	**	0.010
TW-121	4.164	*	0.012
Field Dup			
100ppm CH4	96.2	**	**
100ppm C2H4	**	86.7	**
100ppm C2H6	**	**	94.4
Lower Limit of Quantitation			
	0.001	0.003	0.002

Units for samples are mg/L.
Units for standards are parts per million.

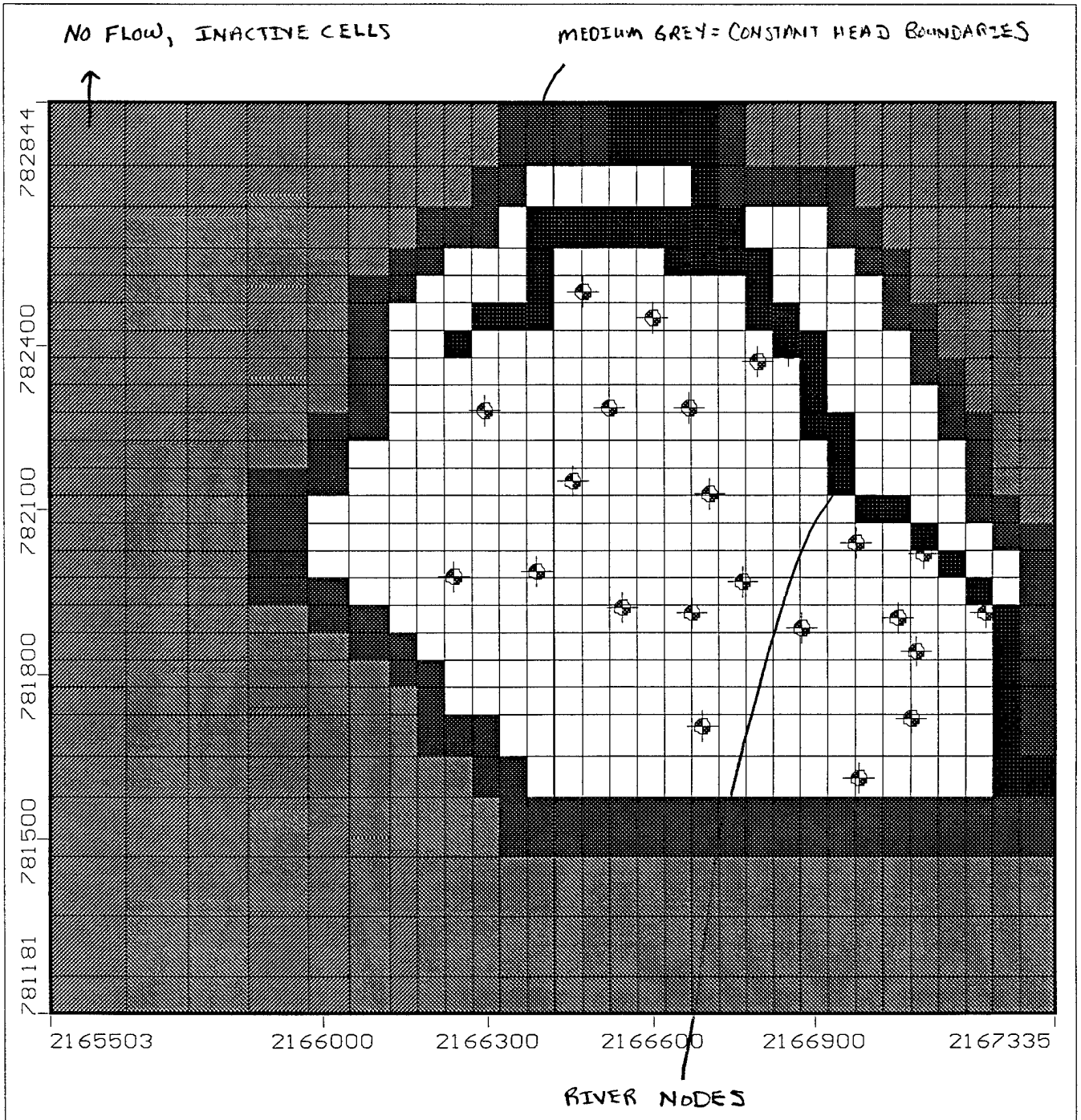
** denotes None Detected.
* denotes Below Limit of Quantitation.

Sample	Methane	Ethylene	Ethane
100ppm CH4	111.5	**	**
100ppm C2H4	**	97.8	**
100ppm C2H6	**	**	91.9
HPHe	**	**	**
Lab Blank	**	**	**
MW1613-1	0.015	**	**
MW1613-2	**	**	**
MW1613-3	**	**	**
MW1613-3A	**	**	**
MW1613-4	0.072	**	**
MW1613-4	0.024	**	**
Lab Dup			
MW1613-4A	*	**	**
MW1613-5	0.102	**	**
MW1613-6	**	**	**
MW1613-7	0.052	**	**
MW1613-8	0.092	**	**
MW1613-8	0.092	**	**
Field Dup			
10ppm CH4	9.5	**	**
MW1613-9	0.009	**	**
MW1613-9A	*	**	**
MW1613-10	**	**	**
MW1613-11	0.138	**	**
MW1613-12	0.991	**	**
MW1613-12	0.708	**	**
Lab Dup			
MW1613-13	0.019	**	**
MW1613-13A	0.001	**	**
MW1613-14	*	**	**
MW1613-14A	**	**	**
MW1613-15	**	**	**
MW1613-15	**	**	**
Field Dup			
100ppm CH4	88.2	**	**
100ppm C2H4	**	99.0	**
100ppm C2H6	**	**	87.7
MW1613-15A	**	**	**
MW1613-16	0.481	**	**
MPA	6.952	**	**
MPB	3.378	**	**
MPC	0.070	*	0.005
MPC	0.077	*	0.002
Lab Dup			
MPD	1.631	**	**
MPE	0.029	**	**
TMP-1	0.001	**	**
TMP-2	0.341	*	**
TMP-3	0.186	*	**
TMP-3	0.195	*	**
Field Dup			
100ppm CH4	91.1	**	**
100ppm C2H4	**	88.3	**
100ppm C2H6	**	**	89.3
Lower Limit of Quantitation	0.001	0.003	0.002

Units for samples are mg/L.
Units for standards are parts per million.
** denotes None Detected.
* denotes Below Limit of Quantitation.

APPENDIX C

MODEL INPUT PARAMETERS, MODEL OUTPUT AND SUPPORTING FIGURES, AND CALCULATIONS RELATED TO MODEL CALIBRATION.

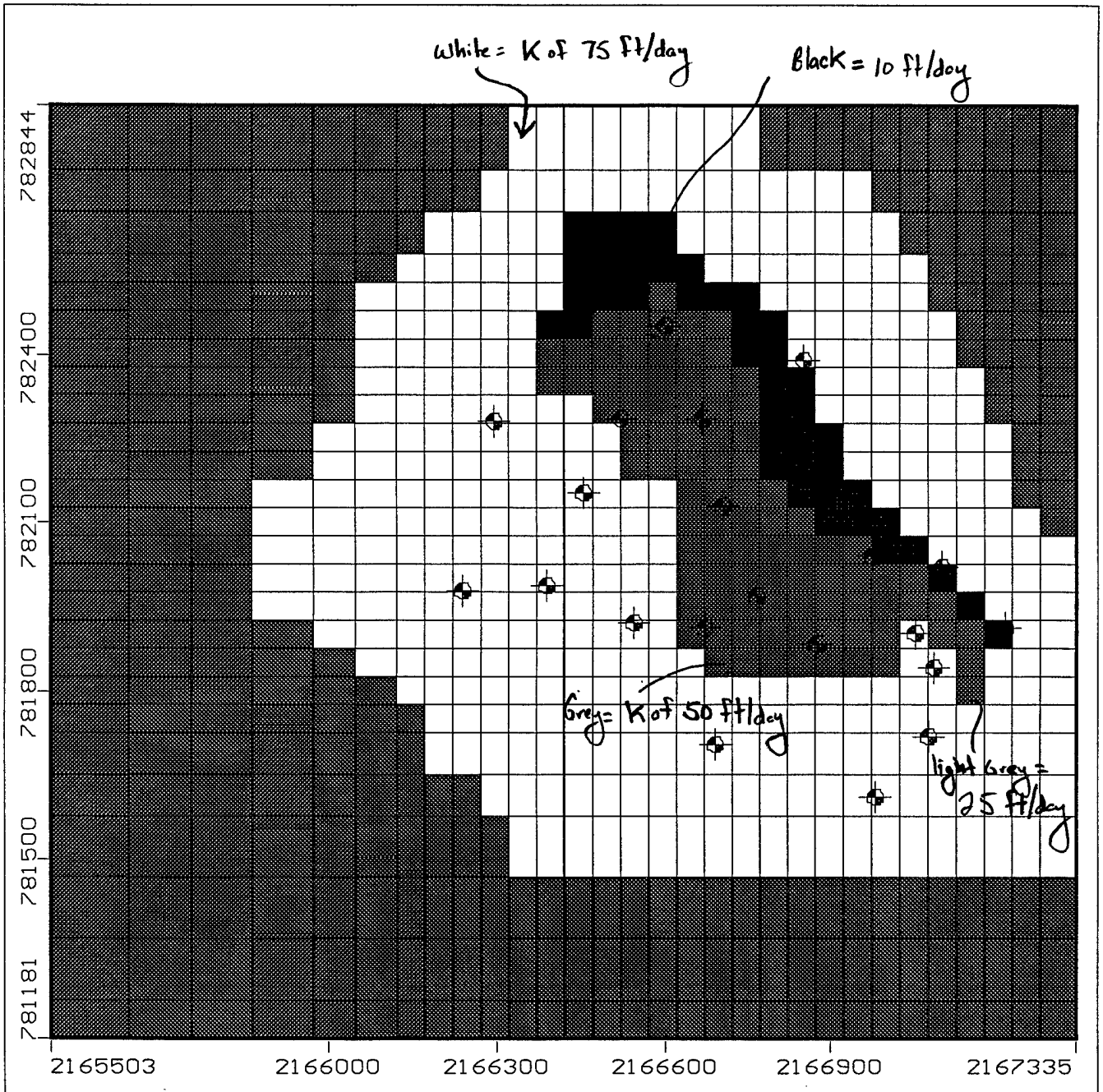


Parsons Eng Science, Inc — Denver, CO
28 Apr 98

MODEL BOUNDARIES

Visual MODFLOW v.2.50, (C) 1995–1997
Waterloo Hydrogeologic Software
NC: 31 NR: 26 NL: 1
Current Layer: 1

SHAW AFB, OU-4

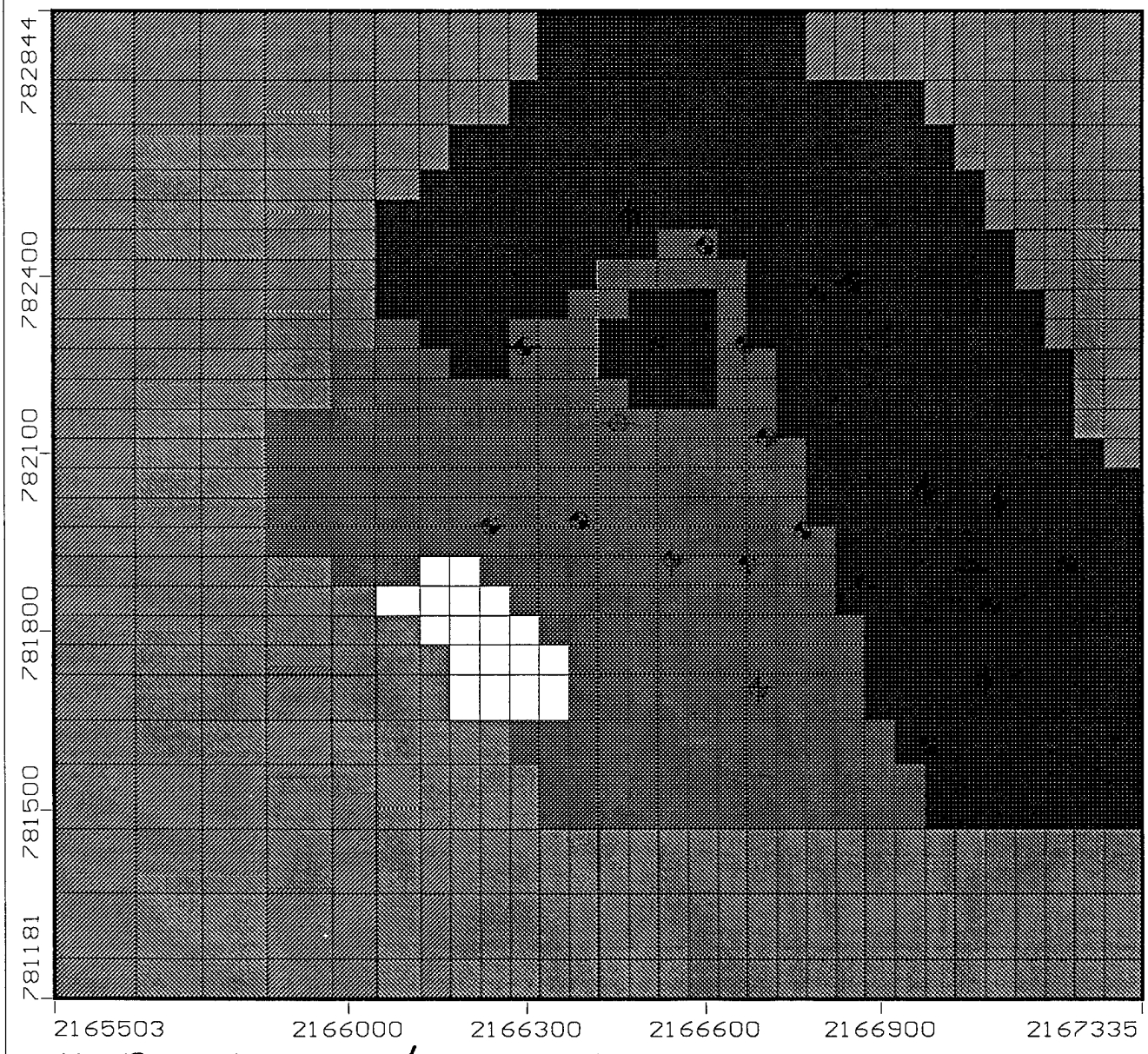


Parsons Eng Science, Inc — Denver, CO
28 Apr 98

HYDRAULIC CONDUCTIVITY, OU-4

Visual MODFLOW v.2.50, (C) 1995–1997
Waterloo Hydrogeologic Software
NC: 31 NR: 26 NL: 1
Current Layer: 1

SHAW AFB, OU-4



WHITE = 0 inches recharge/year

LIGHT GREY WITHIN BOUNDARIES = 40 inches recharge/year

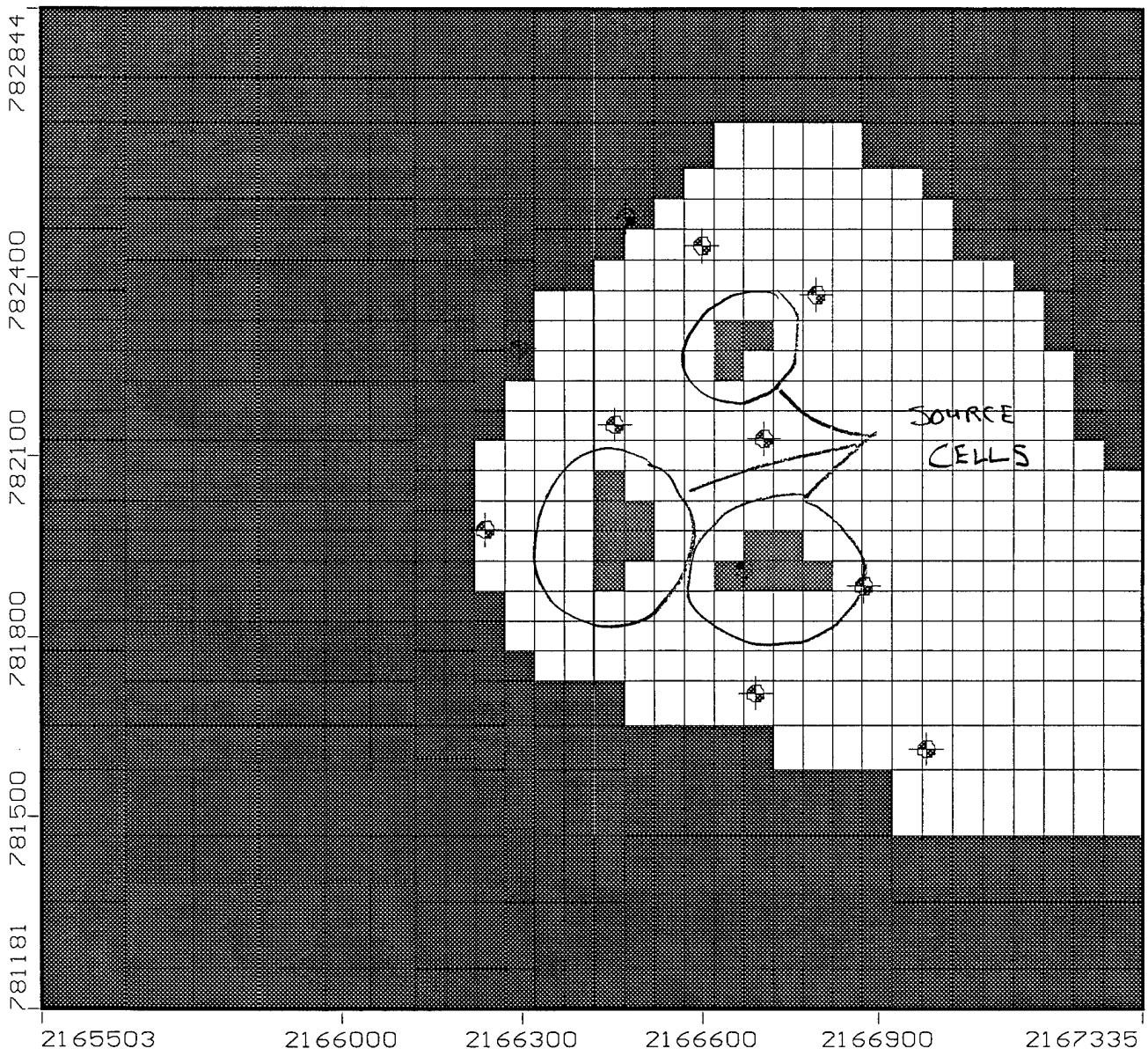
BLACK = 12 INCHES RECHARGE/YEAR

Parsons Eng Science, Inc – Denver, CO
28 Apr 98

MODEL RECHARGE ZONES

Visual MODFLOW v.2.50, (C) 1995–1997
Waterloo Hydrogeologic Software
NC: 31 NR: 26 NL: 1
Current Layer: 1

SHAW AFB, OU-4

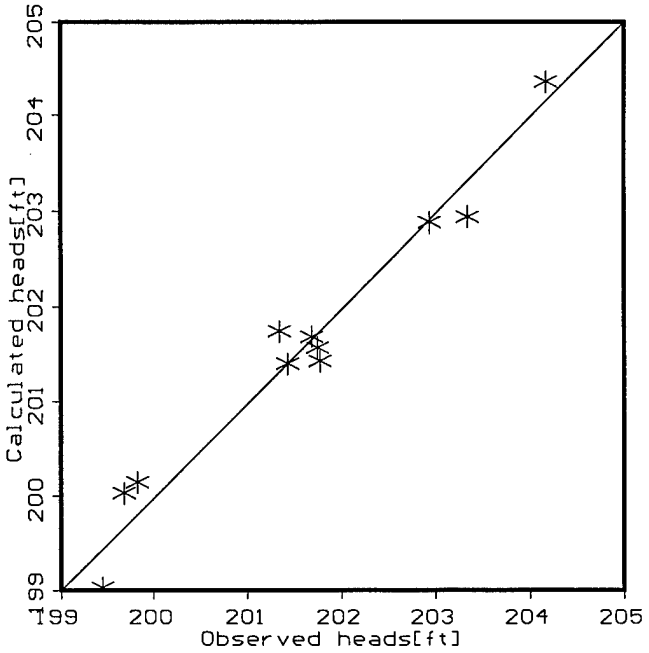


Parsons Eng Science, Inc — Denver, CO
28 Apr 98

SOURCE CELLS FOR CAH CONTAMINATION

Visual MODFLOW v.2.50, (C) 1995–1997
Waterloo Hydrogeologic Software
NC: 31 NR: 26 NL: 1
Current Layer: 1

SHAW AFB, OU-4

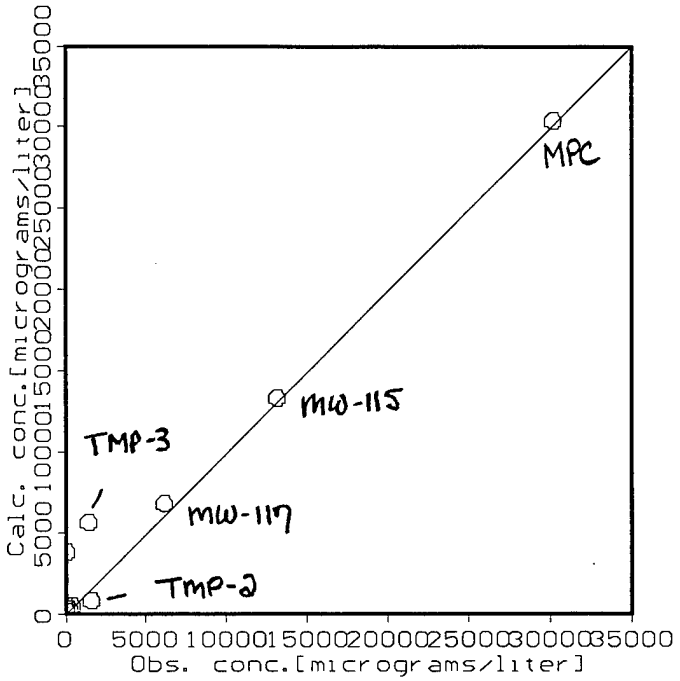


Period: 1
Step: 1

Mean error: -0.0182333 Mean abs. err: 0.244455 RMS error: 0.289165

Parsons Eng Science, Inc — Denver, CO
28 Apr 98
CALCULATED VERSUS OBSERVED HEADS

Visual MODFLOW v.2.50, (C) 1995–1997
Waterloo Hydrogeologic Software
NC: 31 NR: 26 NL: 1
Current Layer: 1
SHAW AFB, OU-4



Period: 1
Step: 1

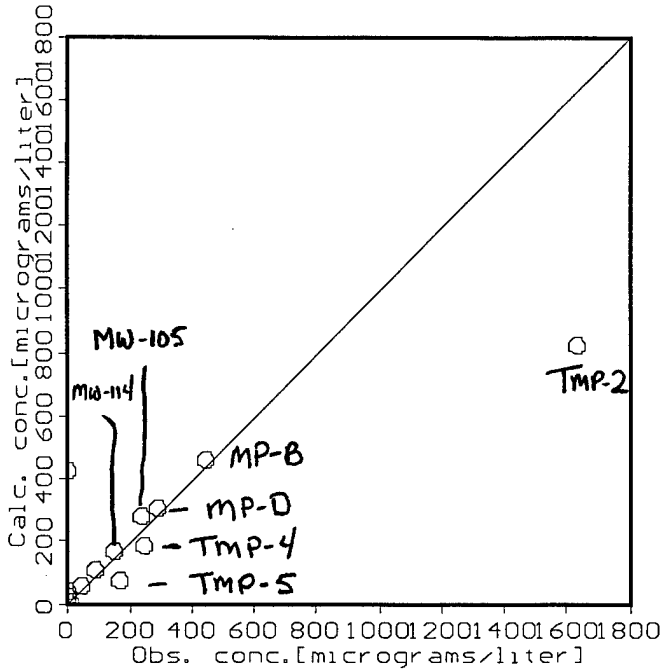
Mean error: 405.45 Mean abs. err: 497.097 RMS error: 1245.47

Parsons Eng Science, Inc – Denver, CO
28 Apr 98

CALCULATED VERSUS OBSERVED
CAH CONCENTRATIONS
(RANGE 0 → 35,000 µg/L)

Visual MODFLOW v.2.50, (C) 1995–1997
Waterloo Hydrogeologic Software
NC: 31 NR: 26 NL: 1
Current Layer: 1

SHAW AFB, OU-4



Period: 1
Step: 1

Mean error: 405.45 Mean abs. err: 497.097 RMS error: 1245.47

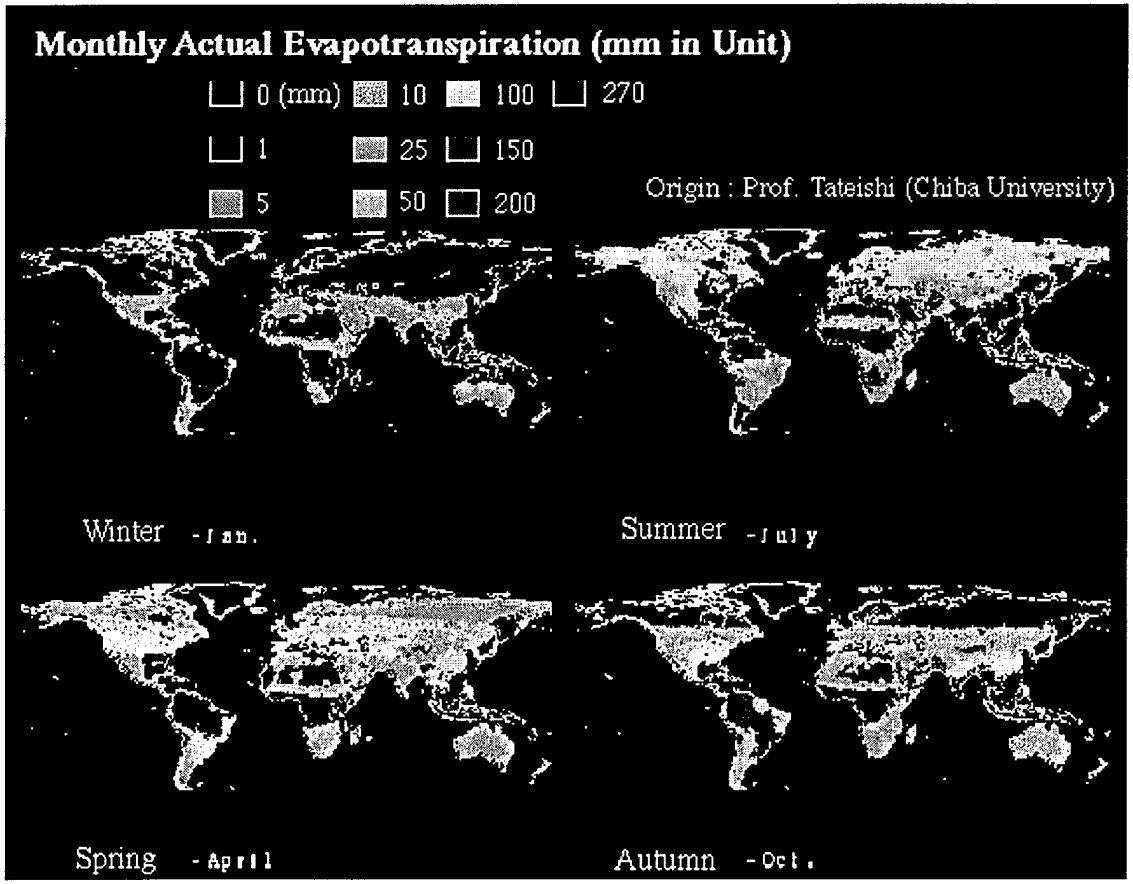
Parsons Eng Science, Inc – Denver, CO 28 Apr 98 CALCULATED VERSUS OBSERVED CAH CONCENTRATIONS	Visual MODFLOW v.2.50, (C) 1995–1997 Waterloo Hydrogeologic Software NC: 31 NR: 26 NL: 1 Current Layer: 1 SHAW AFB, OU-4

(RANGE 0 → 1,800 µg/L)

Originating ID Center : GRID-Tsukuba
Access : Free Access

http://www-cger.nies.go.jp/grid-e/griddat/tateishi/html

Potential Evapotranspiration



This data set is produced by AHN and Tateishi(Remote Sensing and Image Research Center, Chiba University, Japan). It consists of estimated monthly global potential evapotranspriration(PET), evapotranspiration(ET), water balance on 30-minute latitute-longtitude grid. Estimation was based on the Priestley-Taylor method using global data sets including air temperature, albedo, cloudiness, elevation, which are parts of Global Ecosystems Database supplied by NOAA-EPA. Then further calculation was conducted on Thornthwaite method to estimate evapotranspiration using precipitation (supplied by NOAA-EPA) and soil water holding capacity (supplied by GRID-Geneva) data. Almost of all source data were those of approximately 1920 through 1980. The comparison of the latitudinal distribution shows that the larger amount of water surplus in 45N-75N and deficit in 10S-30S rather than those of Legates

ESTIMATING EVAPOTRANSPIRATION RATE TO ESTIMATE A RECHARGE RATE.

(A) SOLVE EVAPOTRANSPIRATION RATE TO USE IN HYDRAULIC MASS BALANCE FOR RECHARGE.

$$ET_p(in) = 0.63\,[50(t-32)/9I]^a \times F(\lambda)$$

Thornthwait's Formula for Estimating Potential Evapotranspiration in., de Marsily, G., Quantitative Hydrogeology, Academic Press, 1986, pp. 403. (Attached)

t = Temp in degrees °F
I = Annual thermal Index = sum of monthly indexes (i)
$a = 6.75 \times 10^{-7} I^3 - 7.71 \times 10^{-5} I^2 + 1.79 \times 10^{-2} I + 0.49239$
$F(\lambda)$ = correction coefficient dependent on latitude : month. Table A.1.1
$i = [(t-32)/9]^{1.514}$

Estimate I

Approximate Latitude = 33.8° N of Myrtle Beach

	MEAN TEMP.*	i **
Jan.	44.1	1.56
Feb.	47.1	2.19
March	55.4	4.25
April	63.1	6.54
May	71.0	9.21
June	77.0	11.94
July	80.5	13.81
August	79.4	12.37
September	74.4	10.45
October	63.9	6.79
Nov.	55.4	4.25
Dec.	47.4	2.26
	Ave = 63.3° F	

$\Sigma i = 84.12 = I$

* Data from Southeast Regional Climate Center in Florence, SC. ** See Attached Table

Estimate a

$$a = 6.75 \times 10^{-7}(84.12)^3 - 7.71 \times 10^{-5}(84.12)^2 + 1.79 \times 10^{-2}(84.12) + 0.49239$$
$$= 0.402 - 0.5456 + 1.506 + 0.49239$$
$$= 1.854$$

Table to Calculate Monthy Evapotranspiration Rates
Myrtle Beach, South Carolina:

Parameters:

I =	84.12
a=	1.854

Month	Mean Temp. (Fahrenheit)	F(λ)	ETp (inches)
January	44.1	0.88	0.37
February	47.1	0.85	0.53
March	55.4	1.03	1.45
April	63.1	1.09	2.61
May	71	1.2	4.37
June	77	1.2	5.70
July	80.5	1.22	6.65
August	79.4	1.16	6.06
September	74.4	1.03	4.38
October	63.9	0.97	2.43
November	55.4	0.87	1.23
December	47.4	0.86	0.56
		Sum=	36.34

(inches of evapotranspiration per year)

The Water Balance for an annual period is:

$$P = Q + EV + \Delta S_s + \Delta S_g + R$$

(in, "Groundwater", Freeze & Cherry, 1979, Prentice Hall, New Jersey)

P = Precipitation
Q = runoff
EV = Evapotranspiration
ΔS_s = change of storage of a surface water reservoir
ΔS_g = Change in storage of a groundwater reservoir
R = Recharge

} inches/year

(A) Since we are averaging many years worth of precipitation data, $\Delta S_s = \Delta S_g = 0$.

(B) Because the source area is in a depression, little chance exists for runoff. Therefore, $Q = 0$

(C) Annual Precipitation is 49.8 inches/year (Section 3)

(D) Evapotranspiration = 36.3 inches/year (Previous Page)

Therefore...

$$49.8 = \cancel{Q}^{\,0} + 36.3 + \cancel{\Delta S_s}^{\,0} + \cancel{\Delta S_g}^{\,0} + R$$

R = 13.5 inches per year.

or

$13.5/49.8 = 0.271$ or 27.1% of Annual Precipitation.

Therefore... it is reasonable to assume that a recharge rate of $\approx$ 30% per year is possible for the Myrtle Beach Site ←

✶ Furthermore, on the basis of Ralph C. Heath's paper ["Classification of Groundwater Systems of the United States", Groundwater, Vol. 30(1), 1992] the estimated aquifer recharge rate for the Atlantic Gulf and Coastal Plain ranges from 2-20 inches/year.

Therefore... 2 → 20 inches/year of recharge is $\approx$ 4 - 40% of the annual precipitation for the Myrtle Beach area. The above calculated value of 30% is within this range.

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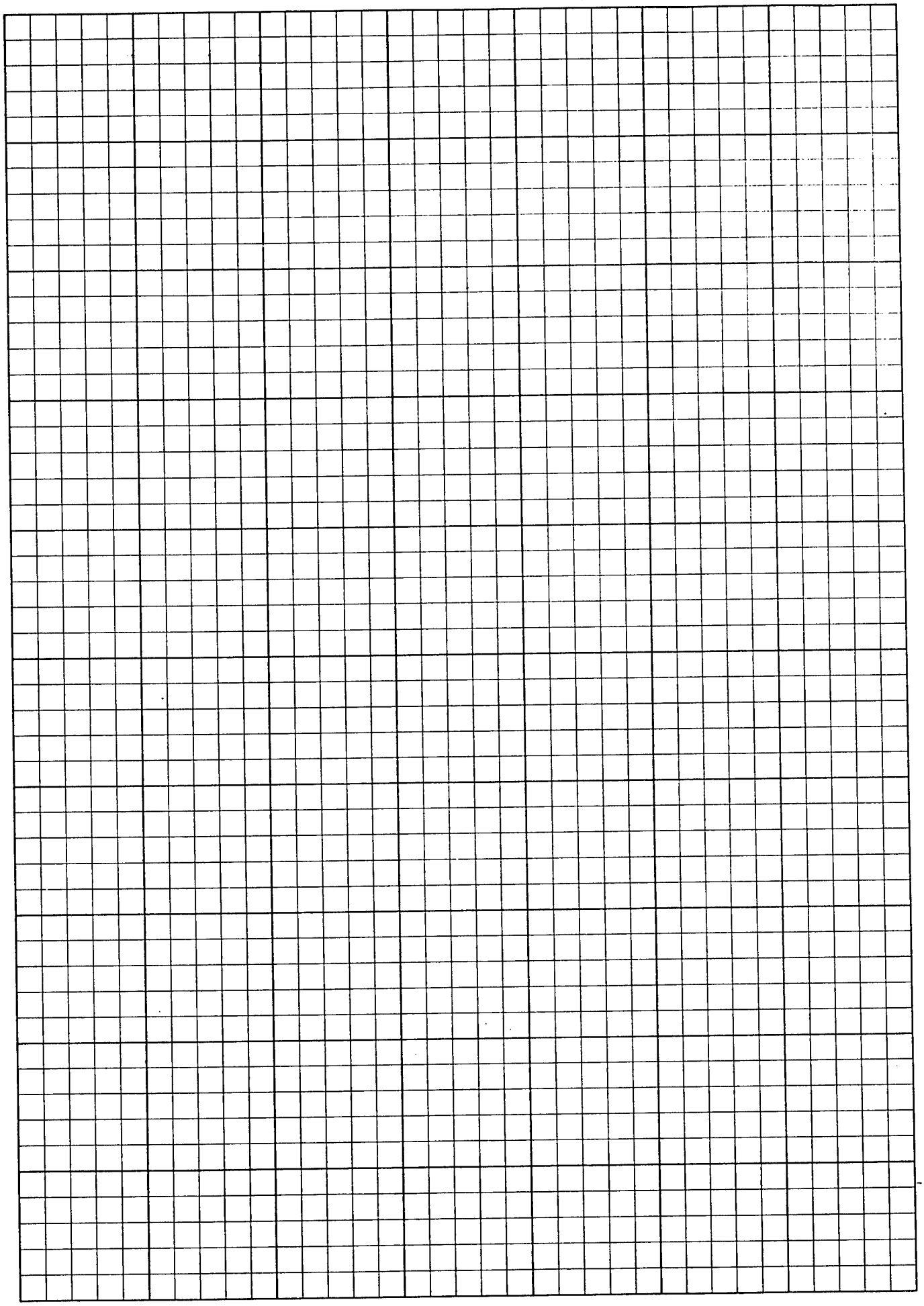


Thornthwaite's Formula for Estimating Potential Evapotranspiration

References:

Thornthwaite, C.W., Transactions, Am. Geophys. Union, April 1944, pp. 686-693

Thornthwaite, C.W., The Geographical Review, Vol.38, 1948, pp. 89-94.

de Marsily, G., Quantitative Hydrogeology, Academic Press, 1986, pp. 403-404.

The Thornthwaite formula for monthly potential evapotranspiration, in millimeters per month, is

$$ET_p(mm) = 16(10\theta/I)^a \times F(\lambda)$$

Where θ is the mean temperature for the month (°C)

$a = 6.75\times10^{-7}I^3 - 7.71\times10^{-5}I^2 + 1.79\times10^{-2}I + 0.49239$

I is an "annual thermal index" equal to the sum of monthly indexes i

$i = (\theta/5)^{1.514}$

$F(\lambda)$ is a correction coefficient which depends on latitude and month. Values of $F(\lambda)$ are given in Table A.1.1 of de Marsily (copy included)

For values of temperature, t, in °F and potential evapotranspiration in inches, $ET_p(in)$, the equations are

$$ET_p(in) = 0.63[50(t-32)/(9I)]^a \times F(\lambda)$$

$$i = [(t-32)/9]^{1.514}$$

Tables 1.1 and 1.2, at the end of this handout, list i for monthly temperatures in °F and °C.

Thornthwaite (1948) states that the equations for potential evapotranspiration given above should only be used for months in which temperatures are 26.5°C (79.7°F) or less. Table 1.3 gives values of ET_p for temperatures from 26.5-38.0 °C (79.7-100.4°F).

Table A.1.1.

Correction Coefficient $F(\lambda)$ Depending on the Latitude and the Month[a]

Lat. N.	J	F	M	A	M	J	J	A	S	O	N	D
0	1.04	0.94	1.04	1.01	1.04	1.01	1.04	1.04	1.01	1.04	1.01	1.04
5	1.02	0.93	1.03	1.02	1.06	1.03	1.06	1.05	1.01	1.03	0.99	1.02
10	1.00	0.91	1.03	1.03	1.08	1.06	1.08	1.07	1.02	1.02	0.98	0.99
15	0.97	0.91	1.03	1.04	1.11	1.08	1.12	1.08	1.02	1.01	0.95	0.97
20	0.95	0.90	1.03	1.05	1.13	1.11	1.14	1.11	1.02	1.00	0.93	0.94
25	0.93	0.89	1.03	1.06	1.15	1.14	1.17	1.12	1.02	0.99	0.91	0.91
26	0.92	0.88	1.03	1.06	1.15	1.15	1.17	1.12	1.02	0.99	0.91	0.91
27	0.92	0.88	1.03	1.07	1.16	1.15	1.18	1.13	1.02	0.99	0.90	0.90
28	0.91	0.88	1.03	1.07	1.16	1.16	1.18	1.13	1.02	0.98	0.90	0.90
29	0.91	0.87	1.03	1.07	1.17	1.16	1.19	1.13	1.03	0.98	0.90	0.89
30	0.90	0.87	1.03	1.08	1.18	1.17	1.20	1.14	1.03	0.98	0.89	0.88
31	0.90	0.87	1.03	1.08	1.18	1.18	1.20	1.14	1.03	0.98	0.89	0.88
32	0.89	0.86	1.03	1.08	1.19	1.19	1.21	1.15	1.03	0.98	0.88	0.87
33	0.88	0.86	1.03	1.09	1.19	1.20	1.22	1.15	1.03	0.97	0.88	0.86
34	0.88	0.85	1.03	1.09	1.20	1.20	1.22	1.16	1.03	0.97	0.87	0.86
35	0.87	0.85	1.03	1.09	1.21	1.21	1.23	1.16	1.03	0.97	0.86	0.85
36	0.87	0.85	1.03	1.10	1.21	1.22	1.24	1.16	1.03	0.97	0.86	0.84
37	0.86	0.84	1.03	1.10	1.22	1.23	1.25	1.17	1.03	0.97	0.85	0.83
38	0.85	0.84	1.03	1.10	1.23	1.24	1.25	1.17	1.04	0.96	0.84	0.83
39	0.85	0.84	1.03	1.11	1.23	1.24	1.26	1.18	1.04	0.96	0.84	0.82
40	0.84	0.83	1.03	1.11	1.24	1.25	1.27	1.18	1.04	0.96	0.83	0.81
41	0.83	0.83	1.03	1.11	1.25	1.26	1.27	1.19	1.04	0.96	0.82	0.80
42	0.82	0.83	1.03	1.12	1.26	1.27	1.28	1.19	1.04	0.95	0.82	0.79
43	0.81	0.82	1.02	1.12	1.26	1.28	1.29	1.20	1.04	0.95	0.81	0.77
44	0.81	0.82	1.02	1.13	1.27	1.29	1.30	1.20	1.04	0.95	0.80	0.76
45	0.80	0.81	1.02	1.13	1.28	1.29	1.31	1.21	1.04	0.94	0.79	0.75
46	0.79	0.81	1.02	1.13	1.29	1.31	1.32	1.22	1.04	0.94	0.79	0.74
47	0.77	0.80	1.02	1.14	1.30	1.32	1.33	1.22	1.04	0.93	0.78	0.73
48	0.76	0.80	1.02	1.14	1.31	1.33	1.34	1.23	1.05	0.93	0.77	0.72
49	0.75	0.79	1.02	1.14	1.32	1.34	1.35	1.24	1.05	0.93	0.76	0.71
50	0.74	0.78	1.02	1.15	1.33	1.36	1.37	1.25	1.06	0.92	0.76	0.70
Lat. S.												
5	1.06	0.95	1.04	1.00	1.02	0.99	1.02	1.03	1.00	1.05	1.03	1.06
10	1.08	0.97	1.05	0.99	1.01	0.96	1.00	1.01	1.00	1.06	1.05	1.10
15	1.12	0.98	1.05	0.98	0.98	0.94	0.97	1.00	1.00	1.07	1.07	1.12
20	1.14	1.00	1.05	0.97	0.96	0.91	0.95	0.99	1.00	1.08	1.09	1.15
25	1.17	1.01	1.05	0.96	0.94	0.88	0.93	0.98	1.00	1.10	1.11	1.18
30	1.20	1.03	1.06	0.95	0.92	0.85	0.90	0.96	1.00	1.12	1.14	1.21
35	1.23	1.04	1.06	0.94	0.89	0.82	0.87	0.94	1.00	1.13	1.17	1.25
40	1.27	1.06	1.07	0.93	0.86	0.78	0.84	0.92	1.00	1.15	1.20	1.29
42	1.28	1.07	1.07	0.92	0.85	0.76	0.82	0.92	1.00	1.16	1.22	1.31
44	1.30	1.08	1.07	0.92	0.83	0.74	0.81	0.91	0.99	1.17	1.23	1.33
46	1.32	1.10	1.07	0.91	0.82	0.72	0.79	0.90	0.99	1.17	1.25	1.35
48	1.34	1.11	1.08	0.90	0.80	0.70	0.76	0.89	0.99	1.18	1.27	1.37
50	1.37	1.12	1.08	0.89	0.77	0.67	0.74	0.88	0.99	1.19	1.29	1.41

[a] Thornthwaite's formula, from Brochet and Gerbier (1974).

Table 1.1 - Monthly indexes, i, for mean temperature in °C

T°C	0.00	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90
0		0.00	0.01	0.01	0.02	0.03	0.04	0.05	0.06	0.07
1	0.09	0.10	0.12	0.13	0.15	0.16	0.18	0.20	0.21	0.23
2	0.25	0.27	0.29	0.31	0.33	0.35	0.37	0.39	0.42	0.44
3	0.46	0.49	0.51	0.53	0.56	0.58	0.61	0.63	0.66	0.69
4	0.71	0.74	0.77	0.80	0.82	0.85	0.88	0.91	0.94	0.97
5	1.00	1.03	1.06	1.09	1.12	1.16	1.19	1.22	1.25	1.28
6	1.32	1.35	1.39	1.42	1.45	1.49	1.52	1.56	1.59	1.63
7	1.66	1.70	1.74	1.77	1.81	1.85	1.89	1.92	1.96	2.00
8	2.04	2.08	2.11	2.15	2.19	2.23	2.27	2.31	2.35	2.39
9	2.44	2.48	2.52	2.56	2.60	2.64	2.68	2.73	2.77	2.81
10	2.86	2.90	2.94	2.99	3.03	3.08	3.12	3.16	3.21	3.25
11	3.30	3.34	3.39	3.44	3.48	3.53	3.58	3.62	3.67	3.72
12	3.76	3.81	3.86	3.91	3.96	4.00	4.05	4.10	4.15	4.20
13	4.25	4.30	4.35	4.40	4.45	4.50	4.55	4.60	4.65	4.70
14	4.75	4.80	4.86	4.91	4.96	5.01	5.07	5.12	5.17	5.22
15	5.28	5.33	5.38	5.44	5.49	5.55	5.60	5.65	5.71	5.76
16	5.82	5.87	5.93	5.98	6.04	6.10	6.15	6.21	6.26	6.32
17	6.38	6.43	6.49	6.55	6.61	6.66	6.72	6.78	6.84	6.90
18	6.95	7.01	7.07	7.13	7.19	7.25	7.31	7.37	7.43	7.49
19	7.55	7.61	7.67	7.73	7.79	7.85	7.91	7.97	8.03	8.10
20	8.16	8.22	8.28	8.34	8.41	8.47	8.53	8.59	8.66	8.72
21	8.78	8.85	8.91	8.97	9.04	9.10	9.16	9.23	9.29	9.36
22	9.42	9.49	9.55	9.62	9.68	9.75	9.81	9.88	9.95	10.01
23	10.08	10.15	10.21	10.28	10.35	10.41	10.48	10.55	10.61	10.68
24	10.75	10.82	10.89	10.95	11.02	11.09	11.16	11.23	11.30	11.37
25	11.44	11.50	11.57	11.64	11.71	11.78	11.85	11.92	11.99	12.06
26	12.13	12.21	12.28	12.35	12.42	12.49	12.56	12.63	12.70	12.78
27	12.85	12.92	12.99	13.07	13.14	13.21	13.28	13.36	13.43	13.50
28	13.58	13.65	13.72	13.80	13.87	13.94	14.02	14.09	14.17	14.24
29	14.32	14.39	14.47	14.54	14.62	14.69	14.77	14.84	14.92	14.99
30	15.07	15.15	15.22	15.30	15.38	15.45	15.53	15.61	15.68	15.76
31	15.84	15.91	15.99	16.07	16.15	16.23	16.30	16.38	16.46	16.54
32	16.62	16.70	16.77	16.85	16.93	17.01	17.09	17.17	17.25	17.33
33	17.41	17.49	17.57	17.65	17.73	17.81	17.89	17.97	18.05	18.13
34	18.21	18.30	18.38	18.46	18.54	18.62	18.70	18.79	18.87	18.95
35	19.03	19.11	19.20	19.28	19.36	19.44	19.53	19.61	19.69	19.78
36	19.86	19.94	20.03	20.11	20.20	20.28	20.36	20.45	20.53	20.62
37	20.70	20.79	20.87	20.96	21.04	21.13	21.21	21.30	21.38	21.47
38	21.56	21.64	21.73	21.81	21.90	21.99	22.07	22.16	22.25	22.33
39	22.42	22.51	22.59	22.68	22.77	22.86	22.94	23.03	23.12	23.21
40	23.30	23.38	23.47	23.56	23.65	23.74	23.83	23.92	24.00	24.09

Table 1.2 - Monthly indexes, i, for mean temperature in °F

T°F	0.00	0.20	0.40	0.60	0.80	T°F	0.00	0.02	0.04	0.06	0.08
32		0.00	0.01	0.02	0.03	66	7.48	7.55	7.61	7.68	7.75
33	0.04	0.05	0.06	0.07	0.09	67	7.82	7.88	7.95	8.02	8.09
34	0.10	0.12	0.14	0.15	0.17	68	8.16	8.23	8.29	8.36	8.43
35	0.19	0.21	0.23	0.25	0.27	69	8.50	8.57	8.64	8.71	8.78
36	0.29	0.32	0.34	0.36	0.39	70	8.85	8.92	8.99	9.07	9.14
37	0.41	0.44	0.46	0.49	0.51	71	9.21	9.28	9.35	9.42	9.50
38	0.54	0.57	0.60	0.63	0.65	72	9.57	9.64	9.71	9.79	9.86
39	0.68	0.71	0.74	0.77	0.81	73	9.93	10.01	10.08	10.15	10.23
40	0.84	0.87	0.90	0.93	0.97	74	10.30	10.38	10.45	10.52	10.60
41	1.00	1.03	1.07	1.10	1.14	75	10.67	10.75	10.83	10.90	10.98
42	1.17	1.21	1.24	1.28	1.32	76	11.05	11.13	11.21	11.28	11.36
43	1.36	1.39	1.43	1.47	1.51	77	11.44	11.51	11.59	11.67	11.74
44	1.55	1.59	1.62	1.66	1.70	78	11.82	11.90	11.98	12.06	12.13
45	1.75	1.79	1.83	1.87	1.91	79	12.21	12.29	12.37	12.45	12.53
46	1.95	1.99	2.04	2.08	2.12	80	12.61	12.69	12.77	12.85	12.93
47	2.17	2.21	2.26	2.30	2.34	81	13.01	13.09	13.17	13.25	13.33
48	2.39	2.44	2.48	2.53	2.57	82	13.41	13.49	13.58	13.66	13.74
49	2.62	2.67	2.71	2.76	2.81	83	13.82	13.90	13.99	14.07	14.15
50	2.86	2.90	2.95	3.00	3.05	84	14.23	14.32	14.40	14.48	14.57
51	3.10	3.15	3.20	3.25	3.30	85	14.65	14.73	14.82	14.90	14.99
52	3.35	3.40	3.45	3.50	3.55	86	15.07	15.15	15.24	15.32	15.41
53	3.61	3.66	3.71	3.76	3.82	87	15.49	15.58	15.67	15.75	15.84
54	3.87	3.92	3.98	4.03	4.09	88	15.92	16.01	16.10	16.18	16.27
55	4.14	4.19	4.25	4.30	4.36	89	16.36	16.44	16.53	16.62	16.70
56	4.41	4.47	4.53	4.58	4.64	90	16.79	16.88	16.97	17.06	17.14
57	4.70	4.75	4.81	4.87	4.93	91	17.23	17.32	17.41	17.50	17.59
58	4.98	5.04	5.10	5.16	5.22	92	17.68	17.77	17.86	17.94	18.03
59	5.28	5.34	5.40	5.46	5.52	93	18.12	18.21	18.30	18.40	18.49
60	5.58	5.64	5.70	5.76	5.82	94	18.58	18.67	18.76	18.85	18.94
61	5.88	5.94	6.00	6.06	6.13	95	19.03	19.12	19.22	19.31	19.40
62	6.19	6.25	6.31	6.38	6.44	96	19.49	19.58	19.68	19.77	19.86
63	6.50	6.57	6.63	6.70	6.76	97	19.95	20.05	20.14	20.23	20.33
64	6.82	6.89	6.95	7.02	7.08	98	20.42	20.51	20.61	20.70	20.80
65	7.15	7.22	7.28	7.35	7.41	99	20.89	20.99	21.08	21.17	21.27

Table 1.3 - Potential evapotranspiration for temperatures greater than 26.5 °C

T(°C)	ET (mm)	T(°F)	ET (in)
26.5	135.0	79.7	5.315
27.0	139.5	80.6	5.492
27.5	143.7	81.5	5.657
28.0	147.8	82.4	5.819
28.5	151.7	83.3	5.972
29.0	155.4	84.2	6.118
29.5	158.9	85.1	6.256
30.0	162.1	86.0	6.382
30.5	165.2	86.9	6.504
31.0	168.0	87.8	6.614
31.5	170.7	88.7	6.720
32.0	173.1	89.6	6.815
32.5	175.3	90.5	6.902
33.0	177.2	91.4	6.976
33.5	179.0	92.3	7.047
34.0	180.5	93.2	7.106
34.5	181.8	94.1	7.157
35.0	182.9	95.0	7.201
35.5	183.7	95.9	7.232
36.0	184.3	96.8	7.256
36.5	184.7	97.7	7.272
37.0	184.9	98.6	7.280
37.5	185.0	99.5	7.283
38.0	185.0	100.4	7.283

Blaney and Criddle Formula for Consumptive Use (Evapotranspiration)

Reference:

Blaney, H. F. and W. D. Criddle, Determining water requirements in irrigated areas from climatological and irrigation data, Soil Conservation Service Technical Paper 96, revised 1952, pp. 14-18.

The empirical formulas developed by Thornthwaite were based on data for relatively humid areas. For arid areas, requiring irrigation for agriculture, Blaney and Criddle developed an alternative formula that relates potential evapotranspiration to the type of crop planted. Their basic formula is as follows:

$$u = kf$$

where u is the monthly consumptive use (evapotranspiration) in inches

f = (t×p)/100 the monthly consumptive use factor

t = mean monthly temperature, °F

p = monthly percent of daytime hours of the year

k = monthly consumptive use coefficient

A graph of monthly percent of daytime hours of the year is included as well as a table (labeled Table 3) of consumptive use coefficients for various crops, averaged over the growing season. Consumptive use is presumably minimal except during the growing season.

Soil Moisture Retention

The table labeled Table 3 gives estimates of the soil moisture retained in the root zone (soil moisture storage capacity) for various soil types and vegetation types. Note that soil moisture retention increases with decreasing grain size, from 1.2 in/ft for sandy soil to 3.6 in/ft for clayey soil, and with increasing depth of the root zone.

Table 3.--Consumptive-use coefficients (K) for irrigated crops in western States

Crop	Length of growing season or period	Consumptive-use coefficient[1] (K)
Alfalfa	Between frosts	0.80 to 0.85
Alfalfa	Prefrost period	.60
Beans	3 months	.60 to .70
Corn	4 months	.75 to .85
Cotton	7 months	.60 to .65
Flax	7 to 8 months	.80
Grains, small	3 months	.75 to .85
Grain (Spring)	3 months	.70
Grain sorghums	4 to 5 months	.70
Orchard, citrus	7 months	.50 to .65
Orchard, walnuts	Between frosts	.70
Orchard, deciduous	Between frosts	.60 to .70
Pasture, grass	Between frosts	.75
Pasture, Ladino clover	Between frosts	.80 to .85
Peas	2 months	.80
Potatoes	3½ months	.65 to .75
Rice	3 to 5 months	.85 to 1.20
Sugar beets	6 months	.65 to .75
Sugarcane (Puerto Rico)	Annual	.80
Tomatoes	4 months	.70
Truck - small	3 months	.60

[1]Average for the growing season or period. Consumptive-use coefficients vary throughout the growing season (see Table 8). The lower values of K are for coastal areas, the higher values for areas with an arid climate.

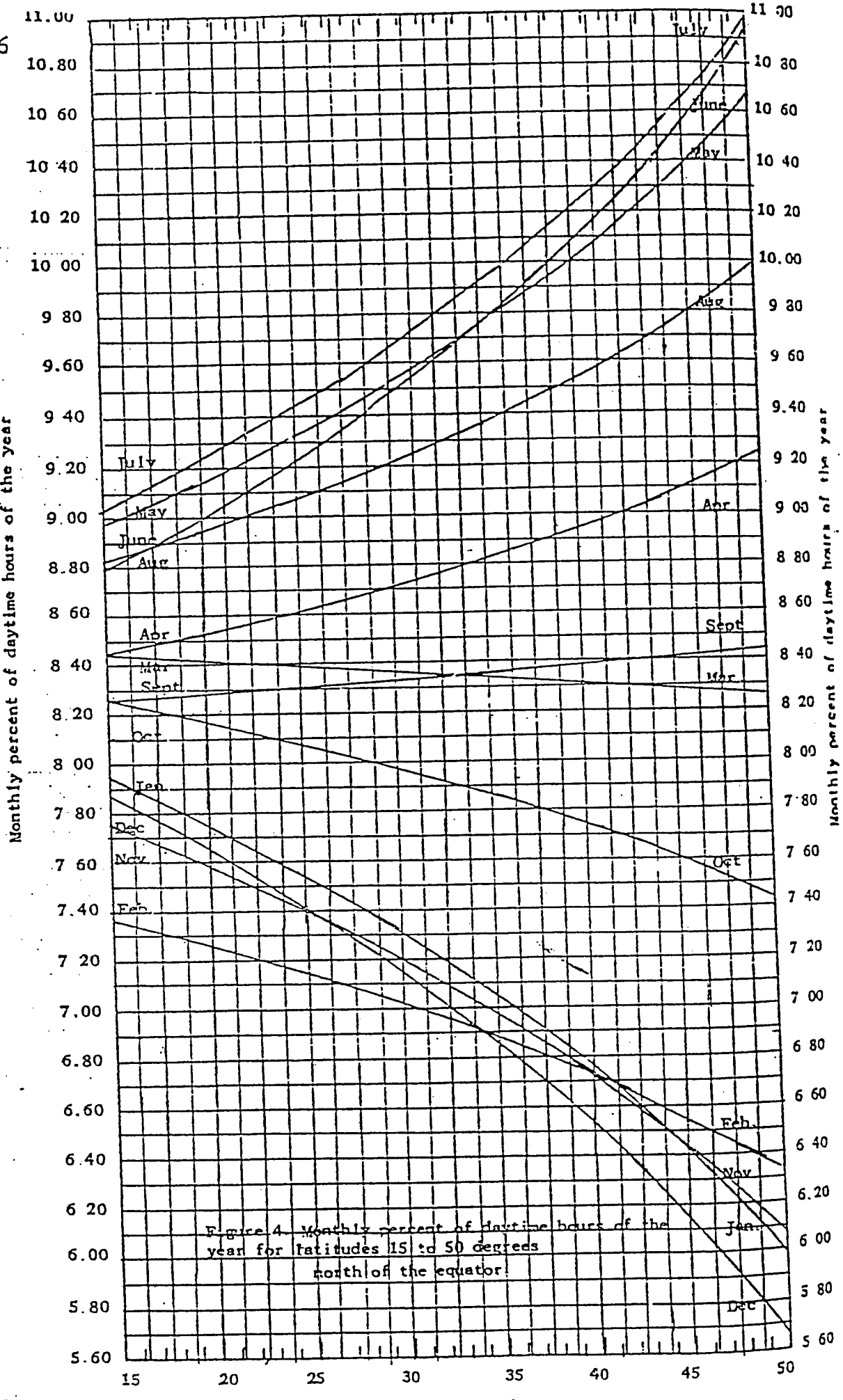


Figure 4. Monthly percent of daytime hours of the year for latitudes 15 to 50 degrees north of the equator.

TABLE 10

PROVISIONAL WATER HOLDING CAPACITIES WITH DIFFERENT COMBINATIONS OF SOIL AND VEGETATION

Soil Type	Available Water		Root Zone		Applicable Soil Moisture Retention Table	
	mm/m	in/ft	m	ft	mm	in
Shallow-rooted crops (spinach, peas, beans, beets, carrots, etc.)						
Fine sand	100	1.2	.50	1.67	50	2.0
Fine sandy loam	150	1.8	.50	1.67	75	3.0
Silt loam	200	2.4	.62	2.08	125	5.0
Clay loam	250	3.0	.40	1.33	100	4.0
Clay	300	3.6	.25	.83	75	3.0
Moderately deep-rooted crops (corn, cotton, tobacco, cereal grains)						
Fine sand	100	1.2	.75	2.50	75	3.0
Fine sandy loam	150	1.8	1.00	3.33	150	6.0
Silt loam	200	2.4	1.00	3.33	200	8.0
Clay loam	250	3.0	.80	2.67	200	8.0
Clay	300	3.6	.50	1.67	150	6.0
Deep-rooted crops (alfalfa, pastures, shrubs)						
Fine sand	100	1.2	1.00	3.33	100	4.0
Fine sandy loam	150	1.8	1.00	3.33	150	6.0
Silt loam	200	2.4	1.25	4.17	250	10.0
Clay loam	250	3.0	1.00	3.33	250	10.0
Clay	300	3.6	.67	2.22	200	8.0
Orchards						
Fine sand	100	1.2	1.50	5.00	150	6.0
Fine sandy loam	150	1.8	1.67	5.55	250	10.0
Silt loam	200	2.4	1.50	5.00	300	12.0
Clay loam	250	3.0	1.00	3.33	250	10.0
Clay	300	3.6	.67	2.22	200	8.0
Closed mature forest						
Fine sand	100	1.2	2.50	8.33	250	10.0
Fine sandy loam	150	1.8	2.00	6.66	300	12.0
Silt loam	200	2.4	2.00	6.66	400	16.0
Clay loam	250	3.0	1.60	5.33	400	16.0
Clay	300	3.6	1.17	3.90	350	14.0

These figures are for mature vegetation. Young cultivated crops, seedlings, and other immature vegetation will have shallower root zones and, hence, have less water available for the use of the vegetation. As the plant develops from a seed or a young sprout to the mature form, the root zone will increase progressively from only a few inches to the values listed above. Use of a series of soil moisture retention tables with successively increasing values of available moisture permits the soil moisture to be determined throughout the growing season.

SUMMARY OF AVERAGE AND WEIGHTED AVERAGE PERCENTAGES OF FOR THE TOTAL CHLORINATED PLUME (INCLUDES ETHENES AND ETHANES)

SITE OU-4 RNA TS

SHAW AFB, SOUTH CAROLINA

(A) Sample ID	(B) Total CAH (µg/L)	(C) PCE/ Total CAH	(D) Column C x Column B	(E) TCE/ Total CAH	(F) Column E	(G) Cis-1,2/ Total CAH	(H) Column G	(I) 1,1-DCE/ Total CAH	(J) Column I	(K) VC/ Total CAH	(L) Column K	(M) TCA/ Total CAH	(N) Column M	(O) 1,1-DCA/ Total CAH	(P) Column O
MW-105	236.5	0.42%	1.00	13.23%	31.30	84.99%	201.00	0.42%	1.00	0.51%	1.20	-	-	0.42%	1.00
MW-106	9.9	-	-	-	-	59.60%	5.90	10.10%	1.00	-		-	-	30.30%	3.00
MW-107	2.6	-	-	-	-	57.69%	1.50	-	-	-		-	-	42.31%	1.10
MW-111	1	-	-	100.00%	1.00	-	-	-	-	-		-	-	-	-
MW-112	90	-	-	-	-	24.44%	22.00	2.44%	2.20	-		1.11%	1.00	72.00%	64.80
MW-112A	0	-	-	-	-	-	-	-	-	-		-	-	-	-
MW-113	2.2	-	-	-	-	54.55%	1.20	-	-	-		-	-	45.45%	1.00
MW-114	148	-	-	-	-	58.85%	87.10	1.42%	2.10	-		-	-	39.73%	58.80
MW-115	13149	0.04%	4.80	0.08%	10.20	12.32%	1620.00	2.80%	368.00	3.16%	416.00	15.44%	2030.00	66.16%	8700.00
MW-115A	4.1	-	-	24.39%	1.00	-	-	51.22%	2.10	-		-	-	24.39%	1.00
MW-116	0	-	-	-	-	-	-	-	-	-		-	-	-	-
MW-116A	0	-	-	-	-	-	-	-	-	-		-	-	-	-
MW-117	6087.7	0.40%	24.10	3.33%	203.00	7.51%	457.00	2.43%	148.00	1.39%	84.60	77.04%	4690.00	7.90%	481.00
MW-118	1	-	-	-	-	-	-	-	-	-		100.00%	1.00	-	-
TW-101	0	-	-	-	-	-	-	-	-	-		-	-	-	-
TW-120	0	-	-	-	-	-	-	-	-	-		-	-	-	-
TW-121	56.9	-	-	-	-	53.95%	30.70	12.83%	7.30	26.89%	15.30	-	-	2.64%	1.50
MPA	48	-	-	2.08%	1.00	7.29%	3.50	8.96%	4.30	-		17.50%	8.40	64.17%	30.80
MPB	444	0.23%	1.00	0.29%	1.30	2.39%	10.60	1.06%	4.70	-		92.57%	411.00	3.47%	15.40
MPC	30237.1	0.30%	90.70	2.37%	718.00	15.18%	4590.00	2.47%	748.00	0.10%	30.40	76.07%	23000.00	3.51%	1060.00
MPD	288.3	-	-	26.71%	77.00	53.76%	155.00	0.59%	1.70	-		0.45%	1.30	18.49%	53.30
MPE	7.3	-	-	-	-	67.12%	4.90	-	-	-		13.70%	1.00	19.18%	1.40
TMP-1	0	-	-	-	-	-	-	-	-	-		-	-	-	-
TMP-2	1628.6	0.06%	1.00	0.07%	1.20	20.82%	339.00	7.12%	116.00	1.40%	22.80	4.83%	78.60	65.70%	1070.00
TMP-3	1468.2	0.07%	1.00	0.27%	3.90	10.22%	150.00	2.74%	40.20	4.06%	59.60	4.12%	60.50	78.53%	1153.00
TMP-4	247.1	-	-	0.40%	1.00	68.39%	169.00	1.42%	3.50	3.12%	7.70	0.40%	1.00	26.26%	64.90
TMP-5	163.8	-	-	-	-	25.95%	42.50	1.10%	1.80	70.82%	116.00	-	-	2.14%	3.50
	Average:	0.22%		14.44%		38.06%		6.82%		12.38%		33.60%		32.25%	
	Weighted Average:		0.23%		1.93%		14.53%		2.67%		1.39%		55.75%		23.50%
Migration Pathway Along East/Southeast Migration Lobe															
MPC	**30237.1**	**0.30%**	90.70	**2.37%**	718.00	**15.18%**	4590.00	**2.47%**	748.00	**0.10%**	30.40	**76.07%**	23000.00	**3.51%**	1060.00
MW-115	**13149**	**0.04%**	4.80	**0.08%**	10.20	**12.32%**	1620.00	**2.80%**	368.00	**3.16%**	416.00	**15.44%**	2030.00	**66.16%**	8700.00
TMP-3	**1468.2**	**0.07%**	1.00	**0.27%**	3.90	**10.22%**	150.00	**2.74%**	40.20	**4.06%**	59.60	**4.12%**	60.50	**78.53%**	1153.00
	Average:	0.13%		0.91%		12.57%		2.67%		2.44%		31.87%		49.40%	
	Weighted Average:		0.22%		1.63%		14.18%		2.58%		1.13%		55.94%		24.33%

GROUNDWATER QUALITY DATA SUMMARY
FOR CHLORINATED ETHENES AND ETHANES
SITE OU-4 RNA TS
SHAW AFB, SOUTH CAROLINA

Sample ID	Date Sampled	PCE (µg/L)	TCE (µg/L)	cis-1,2-DCE (µg/L)	trans-1,2-DCE (µg/L)	1,1-DCE (µg/L)	Vinyl Chloride (µg/L)[a/]	1,1,1-TCA (µg/L)	1,1-DCA (µg/L)	Total CAH's (µg/L)
MW-105	5/15/97	1	31.3	201	ND[b/]	1	1.2	ND	1	**236.5**
MW-106	5/14/97	ND	ND	5.9	ND	1	ND	ND	3.0	**9.9**
MW-107	5/14/97	ND	ND	1.5	ND	ND	ND	ND	1.1	**2.6**
MW-111	5/15/97	ND	1	ND	ND	ND	ND	ND	ND	**1**
MW-112	5/16/97	ND	ND	22.0	ND	2.2	ND	1	64.8	**90**
MW-112A	5/16/97	ND	ND	ND	ND	ND	ND	ND	ND	**0**
MW-113	5/16/97	ND	ND	1.2	ND	ND	ND	ND	1	**2.2**
MW-114	5/15/97	ND	ND	87.1	ND	2.1	ND	ND	58.8	**148**
MW-115	5/15/97	4.8	10.2	1620	ND	368	416	2030	8700	**13149**
MW-115A	5/15/97	ND	1	ND	ND	2.1	ND	ND	1	**4.1**
MW-116	5/14/97	ND	ND	ND	ND	ND	ND	ND	ND	**0**
MW-116A	5/14/97	ND	ND	ND	ND	ND	ND	ND	ND	**0**
MW-117	5/15/97	24.1	203	457	ND	148	84.6	4690	481	**6087.7**
MW-118	5/15/97	ND	ND	ND	ND	ND	ND	1	ND	**1**
TW-101	5/14/97	ND	ND	ND	ND	ND	ND	ND	ND	**0**
TW-120	5/17/97	ND	ND	ND	ND	ND	ND	ND	ND	**0**
TW-121	5/17/97	ND	ND	30.7	2.1	7.3	15.3	ND	1.5	**56.9**
MPA	5/16/97	ND	1	3.5	ND	4.3	ND	8.4	30.8	**48**
MPB	5/16/97	1	1.3	10.6	ND	4.7	ND	411	15.4	**444**
MPC	5/16/97	90.7	718	4590	ND	748	30.4	23000	1060	**30237.1**
MPD	5/16/97	ND	77.0	155	ND	1.7	ND	1.3	53.3	**288.3**
MPE	5/17/97	ND	ND	4.9	ND	ND	ND	1	1.4	**7.3**
TMP-1	5/17/97	ND	ND	ND	ND	ND	ND	ND	ND	**0**
TMP-2	5/17/97	1	1.2	339	ND	116	22.8	78.6	1070	**1628.6**
TMP-3	5/17/97	1.0	3.9	150	ND	40.2	59.6	60.5	1153	**1468.2**
TMP-4	5/16/97	ND	1	169	ND	3.5	7.7	1	64.9	**247.1**
TMP-5	5/16/97	ND	ND	42.5	ND	1.8	116	ND	3.5	**163.8**

MPC	**5/16/97**	**90.7**	**718**	**4590**	**ND**	**748**	**30.4**	**23000**	**1060**	
MW-115	**5/15/97**	**4.8**	**10.2**	**1620**	**ND**	**368**	**416**	**2030**	**8700**	
TMP-3	**5/17/97**	**1.0**	**3.9**	**150**	**ND**	**40.2**	**59.6**	**60.5**	**1153**	

SUMMARY OF AVERAGE AND WEIGHTED AVERAGE PERCENTAGES OF INDIVIDUAL CHLORINATED ETHENE AND ETHANE PLUMES

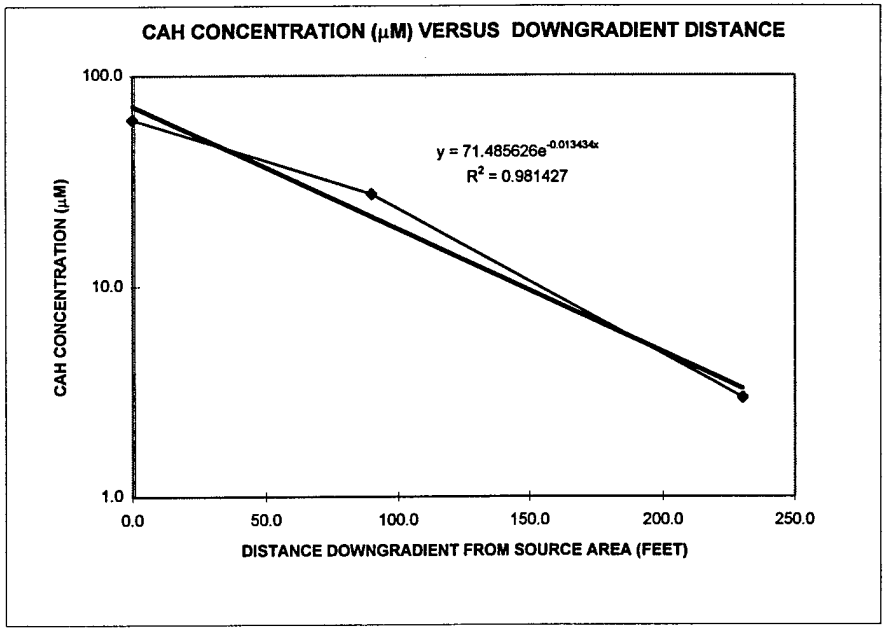
SITE OU-4 RNA TS

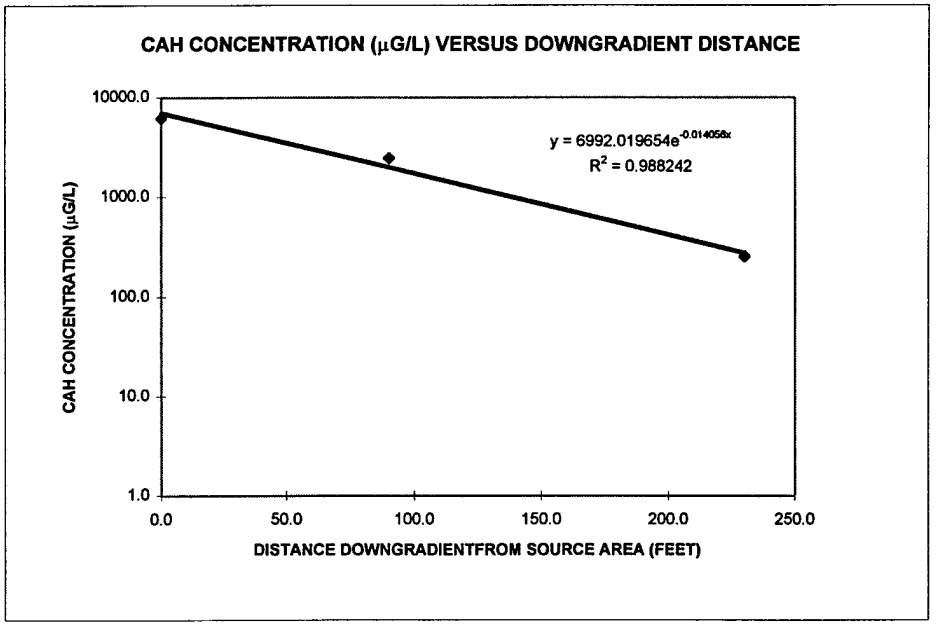
SHAW AFB, SOUTH CAROLINA

(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)	(J)	(K)	(L)	(M)	(N)	(O)	(P)	(Q)
	Total	Total	PCE/		TCE/		Cis-1,2/		1,1-DCE/		VC/		TCA/		1,1-DCA/	
Sample ID	Ethenes (µg/L)	Ethanes (µg/L)	Total Ethene	Column D x Column B	Total Ethene	Column F x Column B	Total Ethene	Column H x Column B	Total Ethene	Column J x Column B	Total Ethene	Column L x Column B	Total Ethane	Column N x Column C	Total Ethane	Column P x Column C
MW-105	235.5	1	0.42%	1.00	13.29%	31.30	85.35%	201.00	0.42%	1.00	0.51%	1.20	-	-	100.00%	1.00
MW-106	6.9	3	-	-	-	-	85.51%	5.90	14.49%	1.00	-	-	-	-	100.00%	3.00
MW-107	1.5	1.1	-	-	-	-	100.00%	1.50	-	-	-	-	-	-	100.00%	1.10
MW-111	1	0	-	-	100.00%	1.00	-	-	-	-	-	-	-	-	-	-
MW-112	24.2	65.8	-	-	-	-	90.91%	22.00	9.09%	2.20	-	-	1.52%	1.00	98.48%	64.80
MW-112A	0	0	-	-	-	-	-		-	-	-	-	-	-	-	-
MW-113	1.2	1	-	-	-	-	100.00%	1.20	-	-	-	-	-	-	100.00%	1.00
MW-114	89.2	58.8	-	-	-	-	97.65%	87.10	2.35%	2.10	-	-	-	-	100.00%	58.80
MW-115	2419	10730	0.20%	4.80	0.42%	10.20	66.97%	1620.00	15.21%	368.00	17.20%	416.00	18.92%	2030.00	81.08%	8700.00
MW-115A	3.1	1	-	-	32.26%	1.00	-	-	67.74%	2.10	-	-	-	-	100.00%	1.00
MW-116	0	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
MW-116A	0	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
MW-117	916.7	5171	2.63%	24.10	22.14%	203.00	49.85%	457.00	16.14%	148.00	9.23%	84.60	90.70%	4690.00	9.30%	481.00
MW-118	0	1	-	-	-	-	-	-	-	-	-	-	100.00%	1.00	-	-
TW-101	0	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TW-120	0	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TW-121	55.4	1.5	-	-	-	-	55.42%	30.70	13.18%	7.30	27.62%	15.30	-	-	100.00%	1.50
MPA	8.8	39.2	-	-	11.36%	1.00	39.77%	3.50	48.86%	4.30	-	-	21.43%	8.40	78.57%	30.80
MPB	17.6	426.4	5.68%	1.00	7.39%	1.30	60.23%	10.60	26.70%	4.70	-	-	96.39%	411.00	3.61%	15.40
MPC	6177.1	24060	1.47%	90.70	11.62%	718.00	74.31%	4590.00	12.11%	748.00	0.49%	30.40	95.59%	23000.00	4.41%	1060.00
MPD	233.7	54.6	-	-	32.95%	77.00	66.32%	155.00	0.73%	1.70	-	-	2.38%	1.30	97.62%	53.30
MPE	4.9	2.4	-	-	-	-	100.00%	4.90	-	-	-	-	41.67%	1.00	58.33%	1.40
TMP-1	0	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TMP-2	480	1148.6	0.21%	1.00	0.25%	1.20	70.63%	339.00	24.17%	116.00	4.75%	22.80	6.84%	78.60	93.16%	1070.00
TMP-3	254.7	1213.5	0.39%	1.00	1.53%	3.90	58.89%	150.00	15.78%	40.20	23.40%	59.60	4.99%	60.50	95.01%	1153.00
TMP-4	181.2	65.9	-	-	0.55%	1.00	93.27%	169.00	1.93%	3.50	4.25%	7.70	1.52%	1.00	98.48%	64.90
TMP-5	160.3	3.5	-	-	-	-	26.51%	42.50	1.12%	1.80	72.36%	116.00	-	-	100.00%	3.50
		Average:	1.57%		19.48%		73.42%		16.88%		17.76%		40.16%	-	79.90%	
		Weighted Average:		1.10%		9.31%		70.00%		12.88%		6.69%		70.35%		29.65%
Migration Pathway Along East/Southeast Migration Lobe																
MPC	6177.1	24060	**1.47%**	90.70	**11.62%**	718.00	**74.31%**	4590.00	**12.11%**	748.00	**0.49%**	30.40	**95.59%**	23000.00	**4.41%**	1060.00
MW-115	**2419**	**10730**	**0.20%**	4.80	**0.42%**	10.20	**66.97%**	1620.00	**15.21%**	368.00	**17.20%**	416.00	**18.92%**	2030.00	**81.08%**	8700.00
TMP-3	**254.7**	**1213.5**	**0.39%**	1.00	**1.53%**	3.90	**58.89%**	150.00	**15.78%**	40.20	**23.40%**	59.60	**4.99%**	60.50	**95.01%**	1153.00
		Average:	0.69%		4.53%		66.72%		14.37%		13.70%		39.83%		60.17%	
		Weighted Average:		1.09%		8.27%		71.86%		13.06%		5.72%		69.69%		30.31%

ESTIMATED MINIMUM FIRST-ORDER RATE CONSTANT CALCULATION FOR THE CHLORINATED ETHENE CONTAMINATION (Foc = 0.00024)
USING THE METHOD OF BUSCHECK AND ALCANTAR (1995)
MAY, 1997
SITE OU-4 RNA TS
SHAW AFB, SOUTH CAROLINA

Well	Distance Downgradient	PCE (µg/L) May-97	PCE (µM) May-97	TCE (µg/L May-97	TCE (µM) May-97	Total DCE (µg/L) May-97	Total DCE (µM) May-97	VC (µg/L) May-97	VC (µM) May-97	Total CAH (µg/L) May-97	Total CAH (µM) May-97
MPC	0.0	90.7	0.6	718.0	5.5	5338.0	55.1	30.4	0.5	6177.1	61.6
MW-115	90.0	4.8	0.0	10.2	0.1	1988.0	20.5	416.0	6.7	2419.0	27.3
TMP-3	230.0	1.0	0.0	3.9	0.0	190.2	2.0	59.6	1.0	254.7	3.0





Method of Buscheck & Alcantar (1995)

$\lambda = v_c/4\alpha_x([1+2\alpha_x(k/v_x)]^2-1)$

where	v_c =	2.97	ft/day*
	α_x =	50	ft
	k/v =	-0.01343	
therefore	λ =	-1.3103E-02	1/day
	λ =	-1.3103E+00	%/day

*(assumes gw velocity of 3.3 and retardation coefficient of 1.11)

Method of Buscheck & Alcantar (1995)

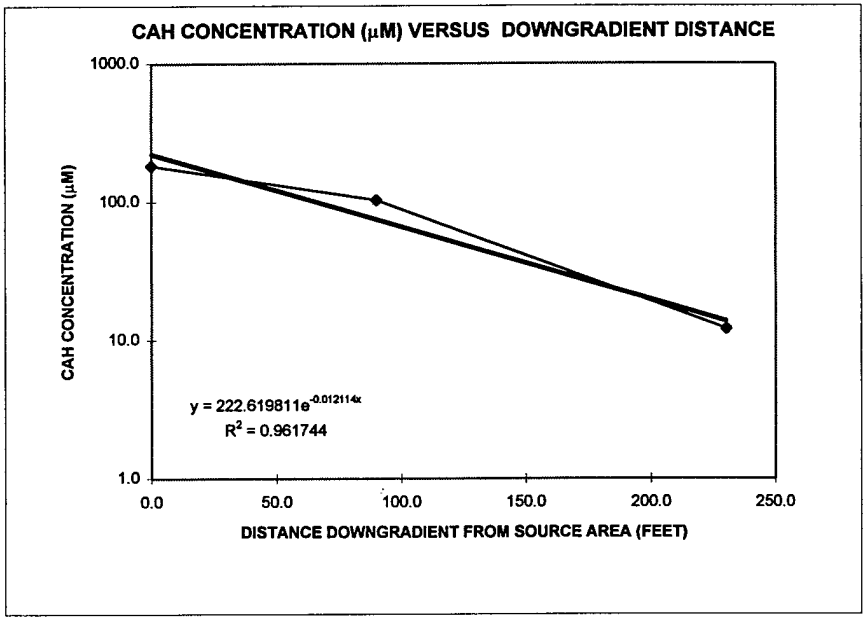
$\lambda = v_c/4\alpha_x([1+2\alpha_x(k/v_x)]^2-1)$

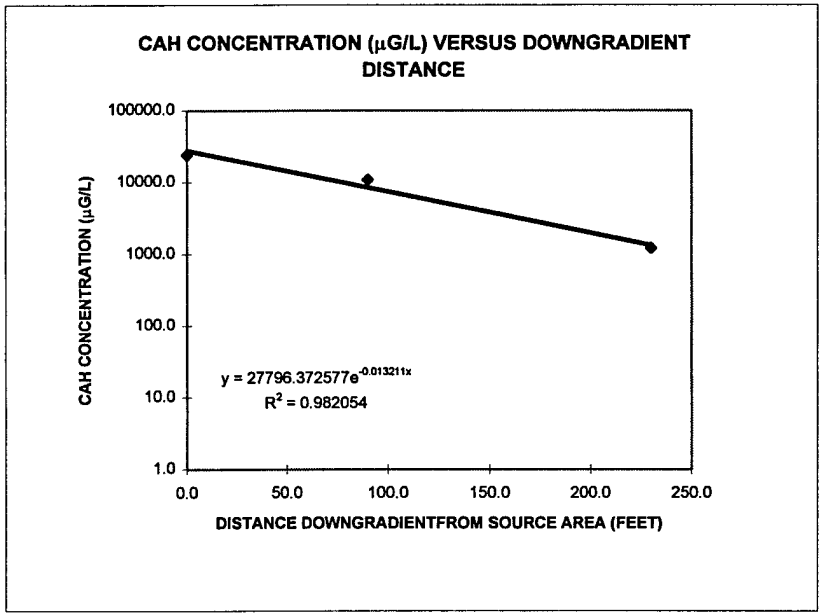
where	v_c =	2.97	ft/day*
	α_x =	50	ft
	k/v =	-0.01405	
therefore	λ =	-1.2414E-02	1/day
	λ =	-1.2414E+00	%/day

*(assumes gw velocity of 3.3 and retardation coefficient of 1.11)

ESTIMATED MINIMUM FIRST-ORDER RATE CONSTANT CALCULATION FOR THE CHLORINATED ETHANE CONTAMINATION (Foc = 0.00024)
USING THE METHOD OF BUSCHECK AND ALCANTAR (1995)
MAY, 1997
SITE OU-4 RNA TS
SHAW AFB, SOUTH CAROLINA

Well	Distance Downgradient	1,1,1-TCA (µg/L) May-97	1,1,1-TCA (µM) May-97	1,1-DCA (µg/L) May-97	1,1-DCA (µM) May-97	Total CAH (µg/L) May-97	Total CAH (µM) May-97
MPC	0.0	23000.0	172.4	1060.0	10.7	24060.0	183.1
MW-115	90.0	2030.0	15.2	8700.0	87.9	10730.0	103.1
TMP-3	230.0	60.5	0.5	1153.0	11.7	1213.5	12.1





Method of Buscheck & Alcantar (1995)

$\lambda = v_c/4\alpha_x([1+2\alpha_x(k/v_x)]^2-1)$

where	v_c =	2.92	ft/day*
	α_x =	50	ft
	k/v =	-0.012114	
therefore	λ =	-1.3948E-02	1/day
	λ =	-1.3948E+00	%/day

*(assumes gw velocity of 3.3 and retardation coefficient of 1.13)

Method of Buscheck & Alcantar (1995)

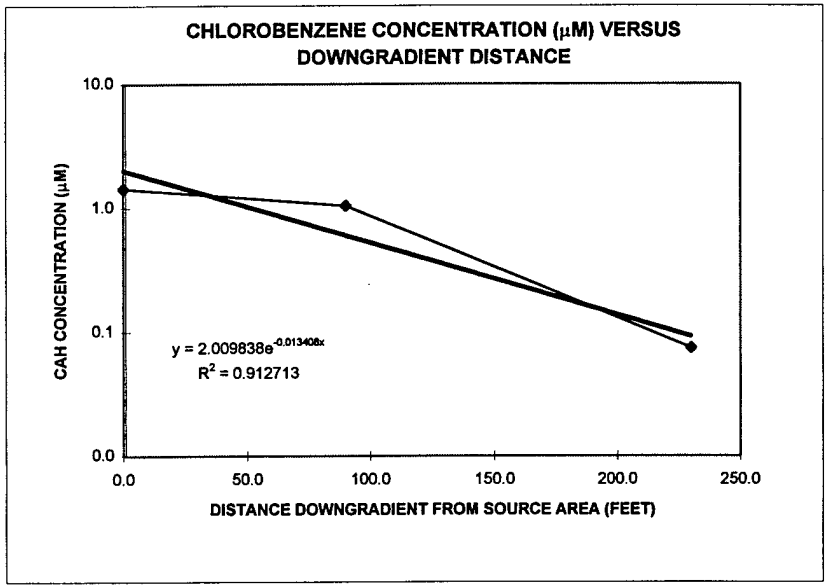
$\lambda = v_c/4\alpha_x([1+2\alpha_x(k/v_x)]^2-1)$

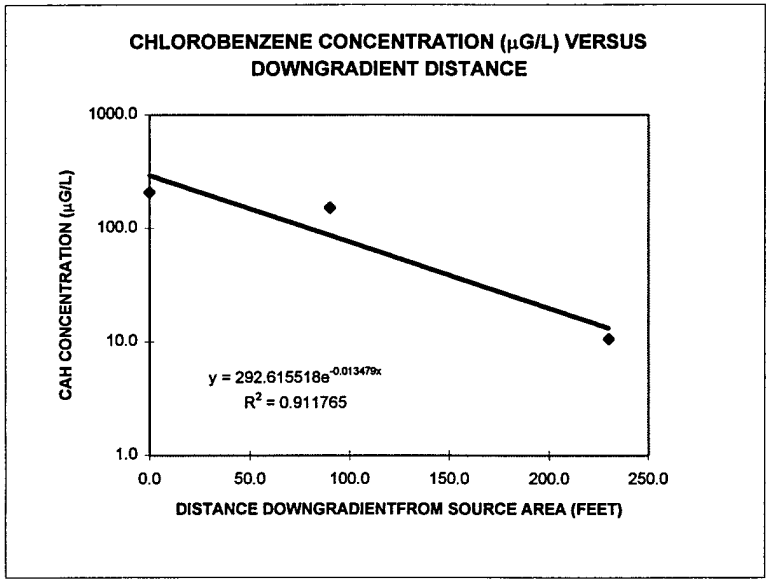
where	v_c =	2.92	ft/day
	α_x =	50	ft
	k/v =	-0.013211	
therefore	λ =	-1.3095E-02	1/day
	λ =	-1.3095E+00	%/day

*(assumes gw velocity of 3.3 and retardation coefficient of 1.13)

ESTIMATED MINIMUM FIRST-ORDER RATE CONSTANT CALCULATION FOR THE CHLORINATED BENZENE CONTAMINATION (Foc = 0.00024)
USING THE METHOD OF BUSCHECK AND ALCANTAR (1995)
MAY, 1997
SITE OU-4 RNA TS
SHAW AFB, SOUTH CAROLINA

Well	Distance Downgradient	1,2-DCB (µg/L) May-97	1,2-DCB (µM) May-97	1,3-DCB (µg/L) May-97	1,3-DCB (µM) May-97	1,4-DCB (µg/L) May-97	1,4-DCB(µM) May-97	CB (µg/L May-97	CB (µM) May-97	Total C-Benz. (µg/L) May-97	Total C-Benz. (µM) May-97
MPC	0.0	117.0	0.8	14.1	0.1	68.2	0.5	9.2	0.1	208.5	1.4
MW-115	90.0	88.9	0.6	11.6	0.1	46.4	0.3	4.9	0.0	151.8	1.0
TMP-3	230.0	6.3	0.0	0.0	0.0	3.3	0.0	1.0	0.0	10.6	0.1





Method of Buscheck & Alcantar (1995)

$$\lambda = v_c/4\alpha_x([1+2\alpha_x(k/v_x)]^2-1)$$

where v_c = 2.56 ft/day*
α_x = 50 ft
k/v = -0.013408

therefore λ = -1.1313E-02 1/day
λ = -1.1313E+00 %/day

*(assumes gw velocity of 3.3 and retardation coefficient of 1.285)

Method of Buscheck & Alcantar (1995)

$$\lambda = v_c/4\alpha_x([1+2\alpha_x(k/v_x)]^2-1)$$

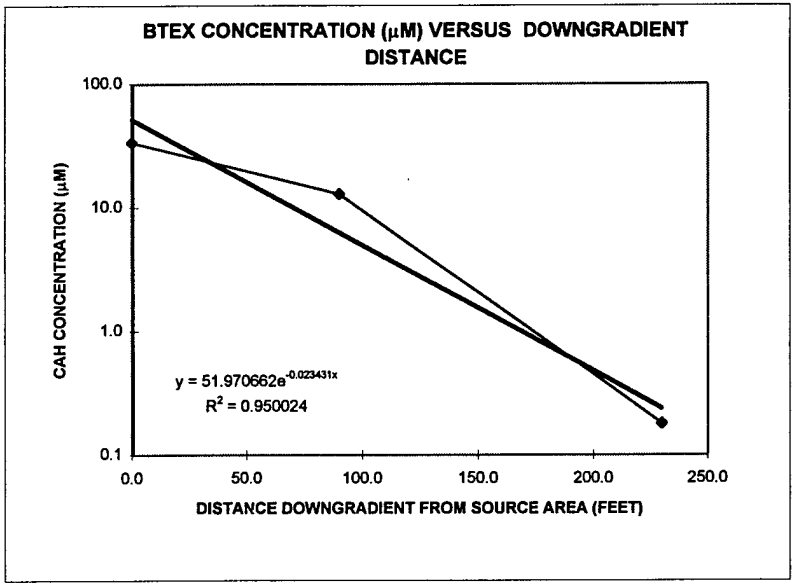
where v_c = 2.56 ft/day
α_x = 50 ft
k/v = -0.013479

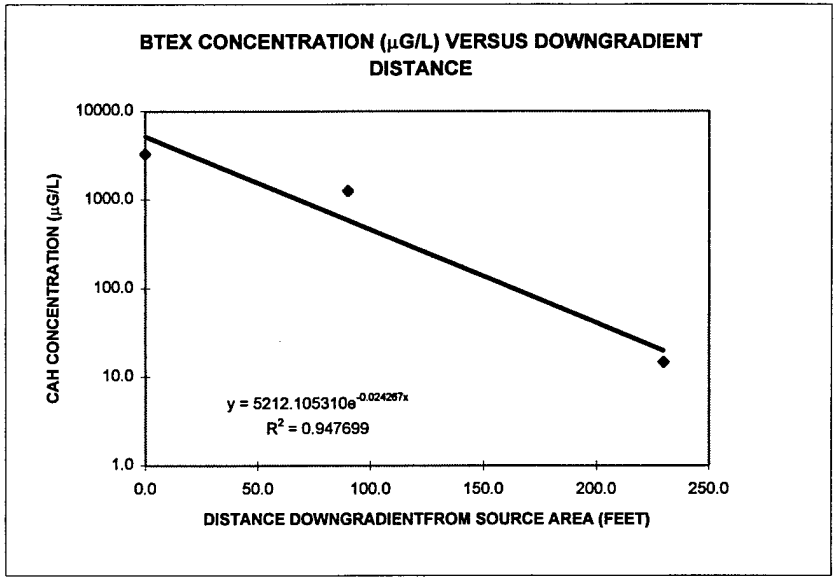
therefore λ = -1.1251E-02 1/day
λ = -1.1251E+00 %/day

*(assumes gw velocity of 3.3 and retardation coefficient of 1.285)

ESTIMATED MINIMUM FIRST-ORDER RATE CONSTANT CALCULATION FOR THE BTEX CONTAMINATION (Foc = 0.00024)
USING THE METHOD OF BUSCHECK AND ALCANTAR (1995)
MAY, 1997
SITE OU-4 RNA TS
SHAW AFB, SOUTH CAROLINA

Well	Distance Downgradient	Benzene (µg/L) May-97	Benzene (µM) May-97	Toluene (µg/L May-97	Toluene (µM) May-97	Eth. Benz. (µg/L) May-97	Eth. Benz. (µM) May-97	Xylenes (µg/L May-97	Xylenes (µM) May-97	Total BTEX (µg/L May-97	Total BTEX. (µM) May-97
MPC	0.0	81.7	1.0	1685.0	18.3	242.0	2.3	1279.0	12.0	3287.7	33.7
MW-115	90.0	157.0	2.0	393.0	4.3	113.0	1.1	588.0	5.5	1251.0	12.9
TMP-3	230.0	12.4	0.2	0.0	0.0	0.0	0.0	2.2	0.0	14.6	0.2





Method of Buscheck & Alcantar (1995)

$\lambda = v_c/4\alpha_x([1+2\alpha_x(k/v_x)]^2-1)$

where	v_c =	2.7	ft/day*
	α_x =	50	ft
	k/v =	-0.02343	
therefore	λ =	1.0849E-02	1/day
	λ =	1.0849E+00	%/day

*(assumes gw velocity of 3.3 and retardation coefficient of 1.22)

Method of Buscheck & Alcantar (1995)

$\lambda = v_c/4\alpha_x([1+2\alpha_x(k/v_x)]^2-1)$

where	v_c =	2.7	ft/day*
	α_x =	50	ft
	k/v =	-0.024267	
therefore	λ =	1.3979E-02	1/day
	λ =	1.3979E+00	%/day

*(assumes gw velocity of 3.3 and retardation coefficient of 1.22)

REDUCTIVE DECHLORINATION RATE FOR CHLORINATED ETHENES (Foc = 0.00024)

MPC > MW-115 > TMP-3

SITE OU-4 RNA TS

SHAW AFB, SOUTH CAROLINA

The following procedures outlined by Moutoux et al. (1996)

Step 1: Enter Observed Contaminant Concentration (mg/L)

Well	PCE	TCE	DCE	VC	Ethene	Total CAHs
MPC	90.7	718.0	5338.0	30.4	0	6177.1
MW-115	4.8	10.2	1988.0	416.0	0	2419.0
TMP-3	1.0	3.9	190.2	59.6	0	254.7

Step 2: Compute Molar Concentrations (micromoles/Liter)

Well	M_{PCE}	M_{TCE}	M_{DCE}	M_{VC}	M_{Ethene}	Total M_{CAHs}
MPC	0.55	5.47	55.06	0.49	0.00	61.56
MW-115	0.03	0.08	20.51	6.66	0.00	27.27
TMP-3	0.01	0.03	1.96	0.95	0.00	2.95

Step 3: Compute Carbon Equivalents

Well	Total M_{CAHs}	x 2	= Ceqi
MPC	61.56		123.13
MW-115	27.27		54.54
TMP-3	2.95		5.90

Step 4: Compute Chlorine Equivalents

Well	M_{PCE} x 4	M_{TCE} x 3	M_{DCE} x 2	M_{VC}	S = $Cleq_i$
MPC	2.19	16.40	110.13	0.49	129.20
MW-115	0.12	0.23	41.02	6.66	48.02
TMP-3	0.02	0.09	3.92	0.95	4.99

Step 5: Compute Corrected CAH Concentrations

$$C_{i,corr} = C_{i-1,corr} \times (Cleq_i / Cleq_{i-1}) \times (Ceq_{i-1} / Ceq_i)$$

Well	$C_{i-1,corr}$	$Cleq_i / Cleq_{i-1}$	Ceq_{i-1} / Ceq_i	$C_{i,corr}$
MPC	6177.10			6177.10
MW-115	6177.10	0.37	2.26	5182.95
TMP-3	5182.95	0.10	9.24	4977.19

Step 6: Plot Exponential Trendline of Contaminant Concentration vs. Time

Well	Distance From Source (ft)	CAH avg. velocity (ft/day)*	CAH Travel Time (day)	$C_{i,corr}$
MPC	0	2.970	0	6177.10
MW-115	90	2.970	30	5182.95
TMP-3	230	2.970	77	4977.19

*Assumes an unretarded velocity of 3.3 feet/day below the upland terrace and a retardation coefficient of 1.11.

Reductive Dechlorination Rate

$C = C_0 e^{-kt}$ where:

C = Corrected Contaminant Concentration (mg/L) at time t (days)

C_0 = Initial Contaminant Concentration (mg/L)

k = Reductive Dechlorination Rate ($days^{-1}$)

from plot: $y = 5957e^{-2.621E-03x}$ $k = -2.621$ E-03 $days^{-1}$

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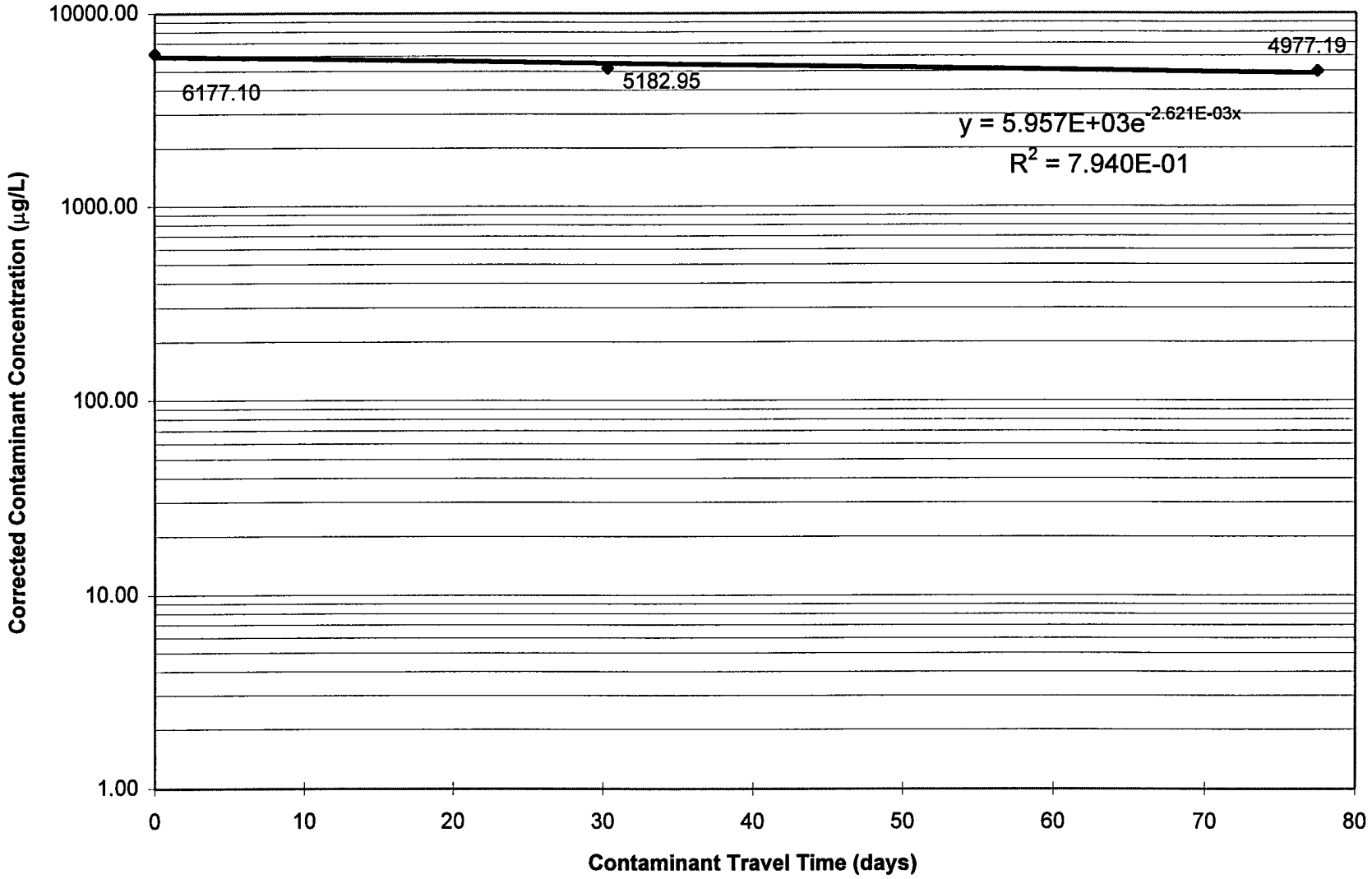
REDUCTIVE DECHLORINATION RATE FOR CHLORINATED ETHENES (Foc = 0.00024)
MPC > MW-115 > TMP-3
MAY, 1994
SITE OU4 RNA TS
SHAW AFB, SOUTH CAROLINA



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REDUCTIVE DECHLORINATION RATE FOR CHLORINATED ETHANES (Foc = 0.00024)

MPC > MW-115 > TMP3

SITE OU-4 RNA TS

SHAW AFB, SOUTH CAROLINA

The following procedures outlined by Moutoux et al. (1996)

Step 1: Enter Observed Contaminant Concentration (µg/L)

Well	1,1,1-TCA	1,1-DCA	1,2-DCA	CA	Total CAHs
MPC	23000.0	1060.0	0.0	0.0	24060.0
MW-115	2030.0	8700.0	0.0	0.0	10730.0
TMP-3	60.5	1153.0	2.1	0.0	1215.6

Step 2: Compute Molar Concentrations (micromoles/Liter)

Well	$M_{1,1,1\text{-TCA}}$	$M_{1,1\text{-DCA}}$	$M_{1,2\text{-DCA}}$	M_{CA}	Total M_{CAHs}
MPC	172.41	10.71	0.00	0.00	183.13
MW-115	15.22	87.91	0.00	0.00	103.13
TMP-3	0.45	11.65	0.02	0.00	12.13

Step 3: Compute Carbon Equivalents

Well	Total M_{CAHs}	x 2	= Ceqi
MPC	183.13		366.25
MW-115	103.13		206.26
TMP-3	12.13		24.25

Step 4: Compute Chlorine Equivalents

Well	$M_{1,1,1\text{-TCA}}$ x 3	$M_{1,1\text{-DCA}}$ x 2	$M_{1,2\text{-DCA}}$ x 2	M_{CA}	$\Sigma = Cleq_i$
MPC	517.24	21.42	0.00	0.00	538.66
MW-115	45.65	175.83	0.00	0.00	221.48
TMP-3	1.36	23.30	0.04	0.00	24.71

Step 5: Compute Corrected CAH Concentrations

$$C_{i,corr} = C_{i-1,corr} \times (Cleq_i / Cleq_{i-1}) \times (Ceq_{i-1} / Ceq_i)$$

Well	$C_{i-1,corr}$	$Cleq_i / Cleq_{i-1}$	Ceq_{i-1} / Ceq_i	$C_{i,corr}$
MPC	24060.00			24060.00
MW-115	24060.00	0.41	1.78	17565.86
TMP-3	17565.86	0.11	8.51	16664.88

Step 6: Plot Exponential Trendline of Contaminant Concentration vs. Time

Well	Distance From Source (ft)	CAH avg. velocity (ft/day)*	CAH Travel Time (day)	$C_{i,corr}$
MPC	0	2.920	0	24060.00
MW-115	30	2.920	10	17565.86
TMP-3	230	2.920	79	16664.88

*Assumes an unretarded velocity of 3.3 feet/day and an average retardation coefficient of 1.13.

Reductive Dechlorination Rate

$C = C_0 e^{-kt}$ where:

C = Corrected Contaminant Concentration (µg/L) at time t (days)

C_0 = Initial Contaminant Concentration (µg/L)

k = Reductive Dechlorination Rate ($days^{-1}$)

from plot: $y = 21110e^{-3.251E-03x}$ $k = -3.251E-03\ days^{-1}$

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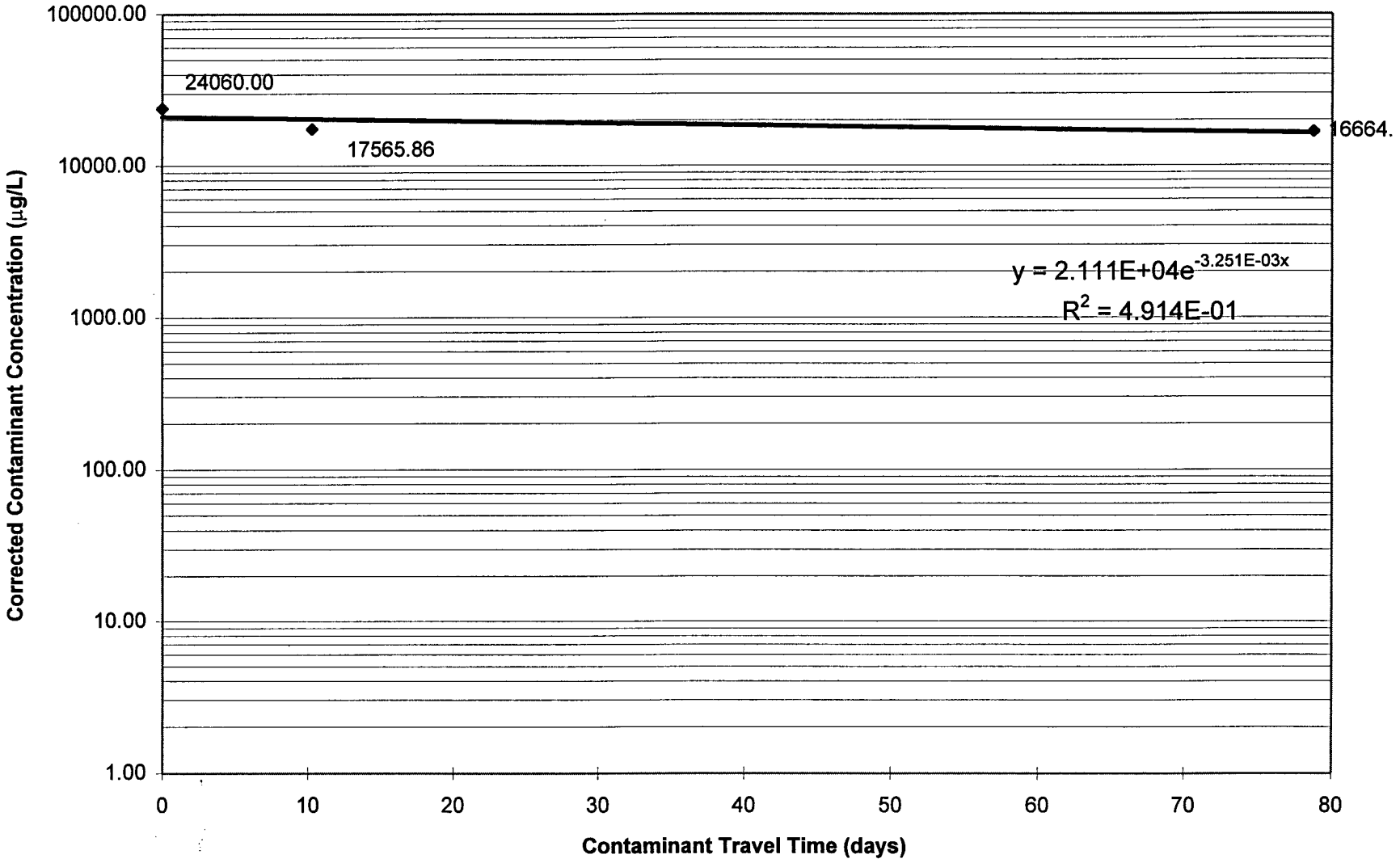
REDUCTIVE DECHLORINATION RATE FOR CHLORINATED ETHANES (Foc = 0.00024)

MPC > MW-115 > TMP-3

MAY, 1997

SITE OU-4 RNA TS

SHAW AFB, SOUTH CAROLINA



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REDUCTIVE DECHLORINATION RATE FOR CHLORINATED BENZENES (Foc = 0.00024)
MPC > MW-115 > TMP-3
SITE OU-4 RNA TS
SHAW AFB, SOUTH CAROLINA

The following procedures outlined by Moutoux et al. (1996)

Step 1: Enter Observed Contaminant Concentration (μg/L)

Well	1,2-DCB	1,3-DCB	1,4-DCB	CB	Total CB's
MPC	117.0	14.1	68.2	9.2	208.5
MW-115	88.9	11.6	46.4	4.9	151.8
TMP-3	6.3	0.0	3.3	0.0	9.6

Step 2: Compute Molar Concentrations (micromoles/Liter)

Well	$M_{1,2\text{-DCB}}$	$M_{1,3\text{-DCB}}$	$M_{1,4\text{-DCB}}$	M_{CB}	Total M_{CBs}
MPC	0.80	0.10	0.46	0.08	1.44
MW-115	0.60	0.08	0.32	0.04	1.04
TMP-3	0.04	0.00	0.02	0.00	0.07

Step 3: Compute Carbon Equivalents

Well	Total M_{CBs}	x 6	= Ceqi
MPC	1.44		8.63
MW-115	1.04		6.26
TMP-3	0.07		0.39

Step 4: Compute Chlorine Equivalents

Well	$M_{1,2\text{-DCB}}$ x 2	$M_{1,3\text{-DCB}}$ x 2	$M_{1,3\text{-DCB}}$ x 2	M_{CB}	$\Sigma = Cleq_i$
MPC	1.59	0.19	0.93	0.08	2.79
MW-115	1.21	0.16	0.63	0.04	2.04
TMP-3	0.09	0.00	0.04	0.00	0.13

Step 5: Compute Corrected CAH Concentrations

$$C_{i,corr} = C_{i-1,corr} \times (Cleq_i / Cleq_{i-1}) \times (Ceq_{i-1} / Ceq_i)$$

Well	$C_{i-1,corr}$	$Cleq_i / Cleq_{i-1}$	Ceq_{i-1} / Ceq_i	$C_{i,corr}$
MPC	208.50			208.50
MW-115	208.50	0.73	1.38	210.12
TMP-3	210.12	0.06	15.97	214.60

Step 6: Plot Exponential Trendline of Contaminant Concentration vs. Time

Well	Distance From Source (ft)	CAH avg. velocity (ft/day)*	CAH Travel Time (day)	$C_{i,corr}$
MPC	0	2.560	0	208.50
MW-115	30	2.560	12	210.12
TMP-3	230	2.560	90	214.60

*Assumes an unretarded velocity of 3.3 feet/day and an average retardation coefficient of 1.285.

Reductive Dechlorination Rate

$C = C_0 e^{-kt}$ where:

C = Corrected Contaminant Concentration (μg/L) at time t (days)
C_0 = Initial Contaminant Concentration (μg/L)
k = Reductive Dechlorination Rate ($days^{-1}$)

from plot: $y = 208.9e^{+3.025E-04x}$ $k = +3.025E\text{-}04\ days^{-1}$

(ERRONEOUS RATE - INCREASING IN VALUE)

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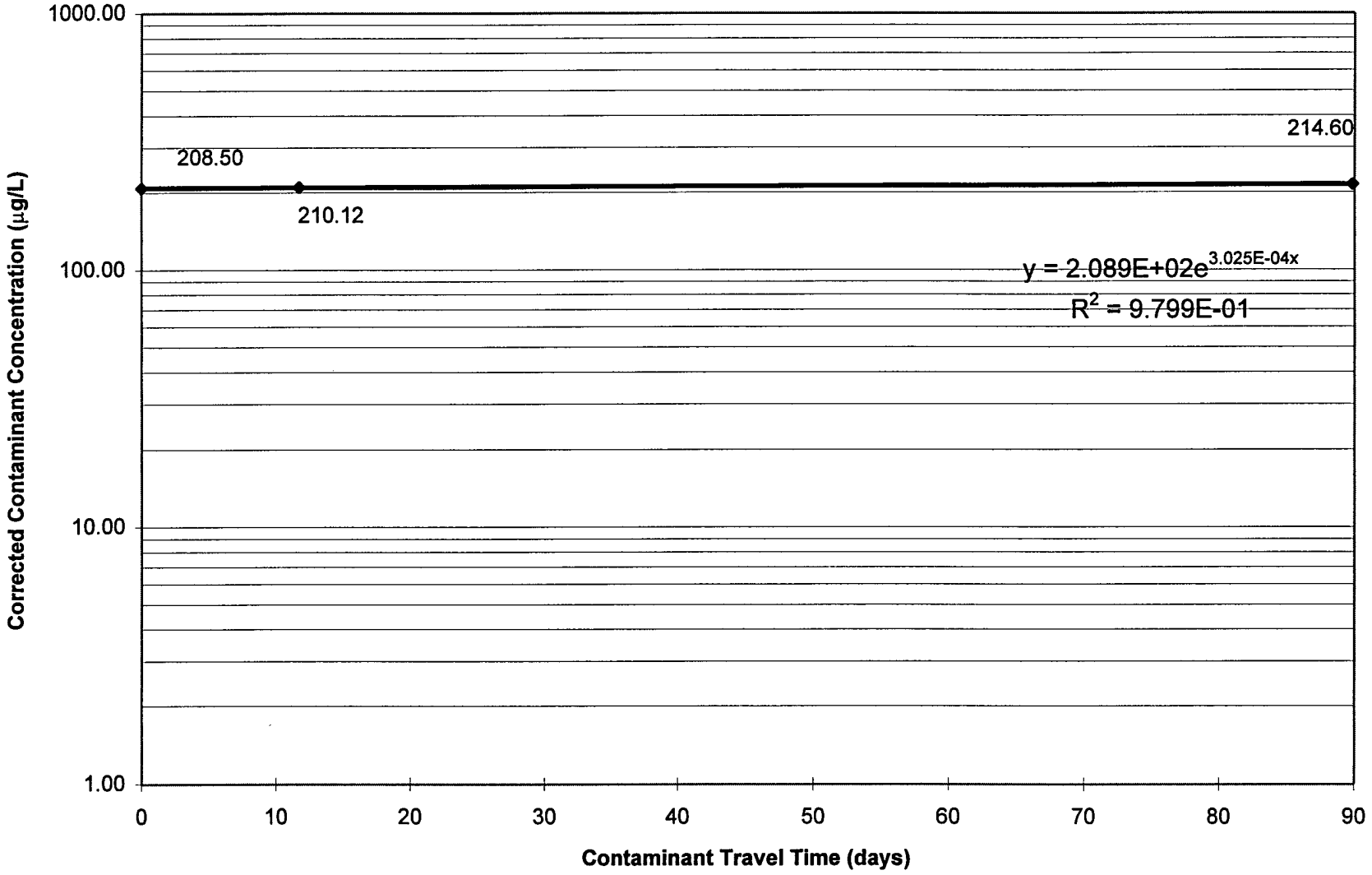
REDUCTIVE DECHLORINATION RATE FOR DICHLOROBENZENES TO MONOCHLOROBENZENE (Foc = 0.00024)

MPC > MW-115 > TMP-3

MAY, 1997

SITE OU-4 RNA TS

SHAW AFB, SOUTH CAROLINA



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APPENDIX D

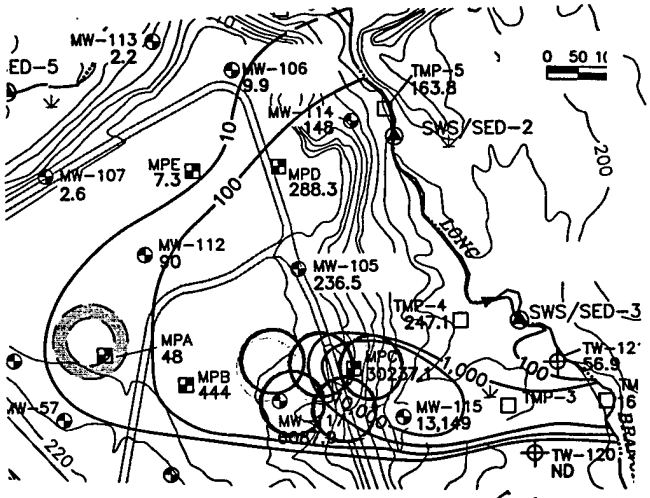
MODEL INPUT FILES

APPENDIX E

COST CALCULATIONS PERTINENT TO REMEDIAL ALTERNATIVES SELECTION

Estimating CAH soil gas conc. & potential SVE system size in source area near MPC/MW-117.

According to the pilot scale chemical oxidation test (IT, 1997), a combined soil gas concentration of 5,030 ppb, or 5.03 ppm was measured at mw-P1. This location was approximately 30' NW of MW-117. This was prior to chemical oxidation treatment. Since



5.03 ppm measured

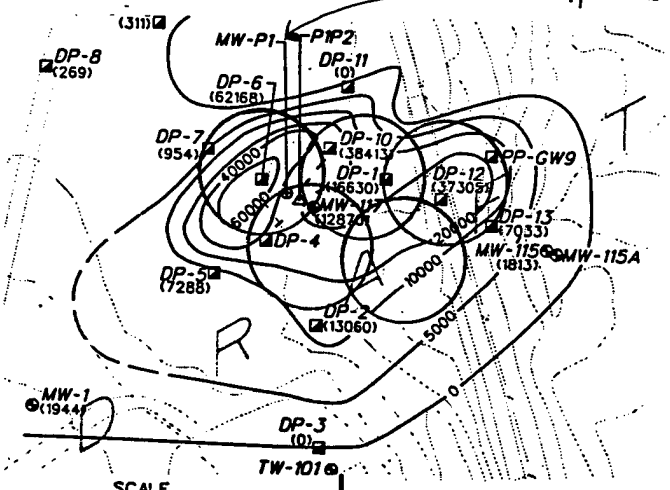


FIGURE 3-2
TOTAL VOCs PRIOR TO TREATMENT

SHAW AIR FORCE BASE
SUMTER, SOUTH CAROLINA

IT INTERNATIONAL TECHNOLOGY CORPORATION

Assume that a 50' Radius of Influence can be achieved. Assume we want to have at least 10 pore volume exchanges for each radius of influence

(1) what is the volume in liters for 10 pore volumes per well per day

$$V = 10' \times 10' \times 0.3 \times \frac{\pi (50)^2}{4}$$

(10 exchanges; 10' treated thickness; 0.3 porosity)

$$V = 58{,}905\ ft^3 \times 28.316 \frac{L}{ft^3} = 1.649 \times 10^6\ L$$

(2) what is the tot. volume for all wells?

$$5 \times 1.649 \times 10^6\ L = 8.2467 \times 10^6\ L$$

(3) If we assume 10 ppm initial voc conc., what will we initially recover per day?

$$8.2467 \times 10^6\ L \times \frac{10\ mg}{L} = 8.2467 \times 10^7\ mg$$

$$= 82\ kg/day.$$

This seems high, but may be achieved in the initial few months.

(4) what blower rate might we need; or size?

$$@\ 8.2467 \times 10^6 \frac{L}{day} \times \frac{0.03532\ ft^3}{L} = 2{,}912{,}273\ ft^3/day$$

$$= 2022.3\ scfm$$

Use a motor with Double capacity – ROTRON DR8, rest of 400 scfm.
DR 8 BD72W

LTM 1 Cost Estimate
Shaw AFB, Site OU4
722450.3705

Author: RTH
Date: 2/17/98
Checked by:
Date:

Summary of Capital and Present Worth Costs

Capital Costs

Design/Construct 4 LTM Wells and initiate LTM Program in 1998 — $12,449
P/F i=7% n=0

Monitoring Costs

Annual Monitoring of 11 wells and 6 surface water stations, 1998-2003 (5 events)

Cost per Event	$22,170	
P/A i=7%, n=0	1998	$22,170
P/A i=7%, n=1	1999	$20,720
P/A i=7%, n=2	2000	$19,364
P/A i=7%, n=3	2001	$18,097
P/A i=7%, n=4	2002	$16,913

Total Present Worth Cost — $97,264

Biennial Monitoring of 11 wells and 6 surface water stations, 2004-2018 (8 events)

Cost per Event	$22,170	
P/A i=7%, n=6	2004	$14,773
P/A i=7%, n=8	2006	$12,903
P/A i=7%, n=10	2008	$11,270
P/A i=7%, n=12	2010	$9,844
P/A i=7%, n=14	2012	$8,598
P/A i=7%, n=16	2014	$7,510
P/A i=7%, n=18	2016	$6,559
P/A i=7%, n=20	2018	$5,729

Total Present Worth Cost — $57,388

Site Management every year (20 years)

Annual Cost	$6,000	
P/A i=7% n=20	PWF = 10.8355273	
	Present Worth Cost	$65,013

Total Capital and Present Worth Costs of LTM Program — $232,114

LTM 1 Cost Estimate
SITE OU4 RNA TS
722450.37050

Author: RTH
Date: 2/17/98
Checked by:
Date:

GW and Surface Water Sampling - 11 wells/6 surface water stations sampled annually till 2002
11 wells/6 surface water stations sampled biennually till 2018.

Sampling Labor	90	hours x	$60	/hour	$5,400
11 Long-Term Monitoring Wells					
6 Surface Water Sample					
4 QA/QC					
21 Total Samples					
Analytical Subcontractor					
	21	CAHs	$150	/each	$3,150
	13	Methane/Ethene	$100	/each	$1,300
	13	Field Parameters	$20	/each	$260
Supplies			$700	lump sum	$700
Travel			$1,300	lump sum	$1,300
Data Management (40 hr x $60hr)			$2,400		$2,400
Data Validation (20 hr x $60/hr)			$1,200		$1,200
Reporting/Project Management Labor					
Word Processing	10	hours x	$25	/hour	$250
CADD	15	hours x	$50	/hour	$750
Reproduction	8	hours x	$20	/hour	$160
Staff Level	50	hours x	$60	/hour	$3,000
Proj. Manager	20	hours x	$80	/hour	$1,600
Editor	5	hours x	$60	/hour	$300
Reporting/Project Management ODCs			$400	lump sum	$400
				Total for 1 Sampling Event	$22,170

Design/Construct 4 LTM Wells & Initiate LTM Program Shaw AFB Site OU-4
(4 shallow wells installed)
Standard Rate Schedule

Billing Category Cost Code/(Billing Category)	Billing Rate	Task 1 (hrs)	Install New LTM/POC Wells ($)	Task 2 (hrs)	Subcon-tracting ($)	Task 3 (hrs)	Reporting & PM ($)
Word Processor 88/(15)	$30	0	$0	5	$150	5	$150
CADD Operator 58/(25)	$47	0	$0	0	$0	0	$0
Technician 42/(50)	$40	8	$320	0	$0	0	$0
Staff Level 16/(65)	$57	20	$1,140	0	$0	0	$0
Project Level 12/(70)	$65	8	$520	0	$0	0	$0
Senior Level 10/(80)	$85	2	$170	0	$0	0	$0
Principal 02/(85)	$97	0	$0	0	$0	0	$0
Total Labor (hrs | $)		38	$2,150	0	$0	0	$0
ODCs							
Phone			$20		$0		$0
Photocopy			$10		$0		$0
Mail			$0		$0		$0
Computer			$0		$0		$0
CAD			$0		$0		$0
WP			$0		$0		$0
Travel			$600		$0		$0
Per Diem			$100		$0		$0
Eqpt. & Supplies			$700		$0		$0
Total ODCs			$1,430		$0		$0
Outside Services							
LTM/POC Well Installation Costs			$8,269		$0		$0
Surveying			$600		$0		$0
Other: Maintain Institutional Controls			$0		$0		$0
Total Outside Services			$8,869		$0		$0

Proposal Estimate	Task 1	Task 2	Task 3
Labor	$2,150	$0	$0
ODC's	$1,430	$0	$0
Outside Services	$8,869	$0	$0
Total by Task	$12,449	$0	$0

Total Labor	$2,150
Total ODCs	$1,430
Total Outside Services	$8,869
Total Project	$12,449

Task 1: Install New LTM wells (4 shallow)
Task 2: Subcontracting/Permitting
Task 3: Reporting/PM per Event.

Shaw AFB, Site OU-4 Backup Calculations

Long-Term Monitoring Well Installation

Misc calculations

Number of LTM wells:		
Number of wells:	2	
Depth each:	35	ft
Number of wells:	2	
Depth each:	25	ft
Total Depth:	120	

Cost calculations

Description	Unit	Qty.	Unit Price	Subtotal	Total
Well Installation					$ 8,269
Mobilization	ea	1	$ 500	$ 500	
Well Installation	ln ft	120	$ 60	$ 7,200	
Soil Disposal	drum	6	$ 100	$ 569	

Installation of SVE Wells

Misc calculations

Number of LTM wells:		
Number of wells:	5	
Depth each:	15	ft
Total Depth:	75	

Cost calculations

Description	Unit	Qty.	Unit Price	Subtotal	Total
Well Installation					$ 5,356
Mobilization	ea	1	$ 500	$ 500	
Well Installation	ln ft	75	$ 60	$ 4,500	
Soil Disposal	drum	4	$ 100	$ 356	

Remedial Alternative 2 Cost Estimate
SHAW AFB, SOUTH CAROLINA
722450.37050

Author: RTH
Date: 2/17/98
Checked by:
Date:

Summary of Present Worth Capital Costs (assuming system installation in 1998)

Installation of Vapor Extraction and Treatment System	$115,856	P/A i=7%, n=0	$115,856
		Total	$115,856

Summary of Present Worth Annual + Biennial + Future Costs (assuming 5-yr operating period 1998-2003)

O&M for SVE system (5 years)

Annual Cost		$55,520
1998	n=0	$55,520
1999	n=1	$51,888
2000	n=2	$48,493
2001	n=3	$45,321
2002	n=4	$42,356

Future Costs (replace regenerative motor once in 2001)

cost per event = $2,500

2001	n=3	$2,041	
		Total =	$2,041

Total Present Worth Cost	$245,619
Total Present Worth Cost of LTM Program (from Alternative 1) (includes site management)	$232,114
Total Annual and Biennial Costs	$477,733
Total Capital + Annual + Biennial + Future Costs for Alternative 2	$593,589

Remedial Alternative 2 Cost Estimate
SHAW AFB, SOUTH CAROLINA
722450.37050

Author: RTH
Date: 2/17/98
Checked by:
Date:

Capital Costs

Installation of the Vapor Extraction System				
SVE Pilot Test (assume existing wells used)			lump sum	$25,000
Design/Procure System	150 hours x	$70	/hour	$10,500
Install SVE Wells		$5,356	lump sum	$5,356
Blower/Shed/Accessories		$20,000	lump sum	$20,000
Thermal Oxidizer Vapor Treatment System (Includes Nat. Gas Costs)	3 months x	$5,500	/month	$16,500
Carbon Adsorption Vapor Treatment System		$12,000	lump sum	$12,000
Electrical Subcontractor		$5,000	lump sum	$5,000
Per Diem	20 days x	$145	/day	$2,900
Travel (1 round trip)		$1,000	lump sum	$1,000
O & M Manual Preparation	40 hours x	$65	/hour	$2,600
Emissions Permitting		$2,000	lump sum	$2,000
Installation/startup Labor	200 hours x	$65	/hour	$13,000
			Subtotal	$115,856

Remedial Alternative 2 Cost Estimate
SHAW AFB, SOUTH CAROLINA
722450.37050

Author: RTH
Date: 2/17/98
Checked by:
Date:

Annual Operating Costs--SVE system (5 years)

Labor		
Weekly System Checks (2 hr x 52 wk/yr x $60/hr)		$6,240
Monthly Sampling (12 hr x 12 mo x $60/hr)		$8,640
Monthly Reporting (8 hr x 12 mo x $60/hr)		$5,760
Maintenance (8 hr x 12 mo x $60/hr)		$5,760
Analytical		
VOCs (air) (2/mo x 12 mo x $250/ea)		$6,000
Sample ship. (2/mo x 12 mo x $30/ea)		$720
Supplies		
Install and Dispose of GAC (assume 2 replacements of 2,000 lb. of GAC/year)		$9,400
misc. (lump sum)		$1,000
Travel (52 trips from Raleigh, NC per year @ $100/ea)		$5,200
Electricity		$5,000
Site Management (Included in LTM portion of Alternative 1)		$0
Recovered Solvent Disposal from Knock Out Tanks ($150/mo x 12 mo)		$1,800
	subtotal	$55,520

APPENDIX E

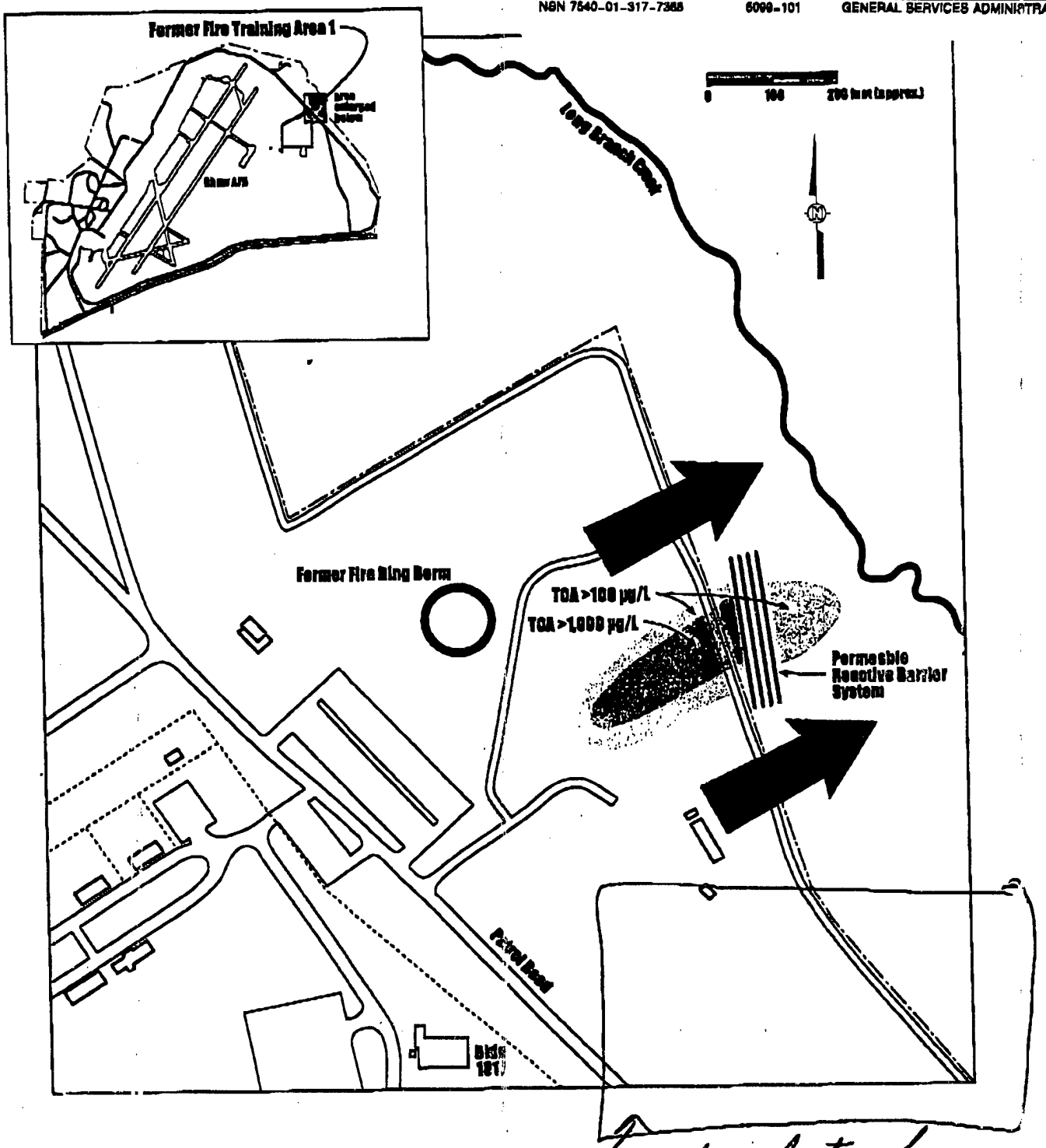
APPROXIMATE LOCATION OF IRON FILINGS WALL (FORWARDED BY MR. RICK ROLLER, 20 CES/CEV ON 9/10/99)

OPTIONAL FORM 99 (7-90)

FAX TRANSMITTAL

To TODD HARRINGTON	From RICK ROLLER
Dept./Agency Parson ES	Phone # SHAW AFB
Fax #	Fax #

NSN 7540-01-317-7368 5099-101 GENERAL SERVICES ADMINISTRATION



Insert a site photo here showing construction of the wall.

APPENDIX F

REPORT COMMENTS AND RESPONSE TO COMMENTS

PARSONS

Parsons Engineering Science, Inc. • A Unit of Parsons Infrastructure & Technology Group Inc.
1700 Broadway, Suite 900 • Denver, Colorado 80290 • (303) 831-8100 • Fax: (303) 831-8208 • www.parsons.com

July 7, 1999

Mr. Jerry Hansen
Technical Program Manager
AFCEE/ERT
3207 North Road, Bldg. 532
Brooks AFB, TX 78235-5363
(210) 536-4353

Subject: Response to Comments for the Draft Remediation by Natural Attenuation Treatability Study for OU-4 (Site FT-1), Shaw Air Force Base, South Carolina.

Dear Mr. Hansen:

Mr. Jon Atkinson of HQ AFCEE/ERC at Brooks AFB, Texas submitted formal comments for the subject report. The following is a summary of the response to comments provided by Parsons ES:

COMMENTS BY: MR. JON ATKINSON, HQ AFCEE/ERC (25 FEBRUARY 1999)

Comment 1: Page V: Suggest listing the appendices in the table of contents.

Response 1: Agreed. The appendices will be listed in the table of contents.

Comment 2: Page 1-2, Sect. 1.1, Sent. 1: Suggest expanding to add "and technical feasibility" after "defensibility".

Response 2: Agreed. The referenced sentence now reads, "...to conduct site characterization and groundwater modeling to evaluate the scientific defensibility *and technical feasibility of* RNA with long-term monitoring (LTM)..."

Comment 3: Page 2-1, Sec. 2, Bullet 3, Line 5: Recommend changing "aromatic acids" to "aromatic hydrocarbons".

Response 3: The reference to aromatic acids was misplaced and misreferenced. The sentence now reads, "...sulfate, total organic carbon (TOC), dissolved hydrogen, and methane/ethane/ethene...."

Comment 4: Page 3-1, Sec. 3.1, Par. 2, Sent. 2: Suggest stating whether Long Branch Creek is perennial or ephemeral.

Response 4: Agreed. The sentence now reads: "The small perennial stream, Long Branch Creek, and an unnamed southwest drainage ditch both border the Base..."

Comment 5: Pages 3-7 and 3-8, Figs 3.3 and 3.4: Suggest adding the vertical exaggeration specifications for the cross sections.

Response 5: Agreed. References for the vertical exaggeration in Figures 3.3 and 3.4 were added.

Comment 6: Page 3-13, Sec. 3.3.2.2, Sent. 1: Typically pumping tests are performed for periods ranging from 24 to 72 hours. Consequently, should "26-minute" be "26-hour"?

Response 6: The reference to a "26-minute" pumping test is correct as stated. This fact was confirmed with Mr. Rick Roller of Shaw AFB on 5/21/99.

Comment 7: Page 4-6, sec. 4.1.2, Sent. 2: To correct terminology, recommend changing "groundwater table" to "water table."

Response 7: Agreed. "Groundwater table" was changed to "water table" to maintain consistency of the use of this term in Section 4.1.2.

Comment 8: Page 4-23, Sec. 4.3.1, Par. 1, Last Line: To better reflect accuracy and certainty of analytical methods here and throughout Section 4.3, suggest reporting results to no more than three significant figures (1930 µg/L).

Response 8: It is the laboratory's responsibility to determine the significant figure placement for analytical data provided in hardcopy format. The data hardcopy is the legally defensible form of data provided to Parsons ES by the laboratory and Parsons ES has chosen to maintain consistency throughout the report by using hardcopy values in all text and tables. Furthermore, utilization of nonrounded hardcopy results helps to avoid reader confusion when reviewing tables and text.

Comment 9: Page 4-24, Table 4.3: To better reflect accuracy and certainty of analytical methods, suggest reporting results to no more than three significant figures (round 340.6 to 341. µg/L.

Response 9: See Response 8.

Comment 10: Page 4-35, Table 4.5: To better reflect accuracy and certainty of analytical methods, suggest reporting results to no more than three significant figures (round 340.6 to 341 µg/L)

Response 10: See Response 8.

Comment 11: Pages 4-50 and 4-53, Sec. 4.4.2.1, Line 10: To improve sentence structure, recommend inserting "from" after "resulted."

Response 11: Agreed. The change was made and the next now reads, "...contaminant plume (MPC and MW-117) may have resulted *from* the chemical oxidation pilot test, which caused a large release...."

Comment 12: Page 4-53 and 4-54, Sec. 4.4.2.1, Line 14: "19.02 mg/L" should be "19.02 nM/L."

Response 12: Agreed. The referenced text now reads "A dissolved hydrogen concentration of 19.02 *nM/L* was measured at MW-112A which is...."

Comment 13: Page 4-61, Sec. 4.6, Par. 3, Line 1: "coocurrence" probably should be "occurrence."

Response 13: Agreed. The sentence now reads, "The *occurrence* of CB and DCB contamination indicates...."

Comment 14: Pages 6-29 and 6-36, Tables 6.3 and 6.4: Four wells are cited under capital costs; however, Section 7.2.1 (p. 7-2) state that three new LTM wells are recommended. This inconsistency needs to be corrected.

Response 14: Parsons ES proposed four new wells at OU4. These four proposed wells include three LTM wells and one sentry well. The proposed sentry well location was accidentally omitted from Figure 7.1 and will be replaced in the final document. Tables 6.3 and 6.4 were clarified by the modification of the first line of descriptive text in each table from, "Design/construct four LTM wells in 1998," to, "Design/construct three LTM wells and one sentry well in 1998." Furthermore, the costing section for Alternative 1 (Section 6.4.1.3) was amended to include a reference to the construction of a sentry well.

Comment 15: Page 7-2, Sec. 7.2, Line 5: To correct the grammar, "consist" should be changed to "consists."

Response 15: Agreed. This change was made to the Final TS.

Comment 16: Page 7-2, Sec. 7.2.1: MW-112 is listed as a proposed LTM well; however, it is not depicted as a proposed LTM well on Figure 7.1.

Response 16: Thank you. Monitoring well MW-112 was marked as a proposed LTM well in Figure 7.1.

Comment 17: Page 7-4, Sec. 7.2.2, Sent. 2: Although this sentence states that a sentry well is proposed about 300 feet east of Long Branch Creek, this sentry

well is not depicted on Figure 7.1. This inconsistency should be resolved.

Response 17: Agreed. See Response 14.

Comment 18: Page 8-2, Sec. 8, Par. 1, Line 5: Suggest changing "DHEC (1997)" to "SCDHEC (1997)."

Response 18: Agreed. DHEC was changed to SCDHEC in the above reference and in other similar references in the TS report.

Comment 19: Page 8-4, Sec. 8

a. Par. 1, Line 1: "affects" should be "effects."

b. Par. 2, Sent. 1: The recommendation of four proposed new monitoring wells contradicts Section 7.2.1 and Figure 7.1 which contain three proposed LTM wells. This inconsistency needs to be resolved.

Response 19:

a. Agreed. "affects" was changed to "effects."

b. This reference is correct. Please see Response 14.

Comment 20: Page 9-6, Sec. 9, Ref. 5: Suggest inserting "South Carolina" in front of "Department."

Response 20: Agreed. This change was made.

COMMENTS BY: MR. RICHARD C. ROLLER, 20 CES/CEV (18 MARCH 1999)

Comment 1: Comments are provided to accept the referenced document as final by Shaw AFB, SC. The statement at the top of page ES-3 should reflect that AFCEE as a result of this investigation and study recommends this particular solution. It should not bind the Air Force, inclusive of Shaw AFB.

Response 1: Agreed. The referenced statement now reads ". The Air Force Center for Environmental Excellence (AFCEE) therefore recommends implementation of soil vapor extraction (SVE)..."

Comment a: Shaw AFB addressed cleanup of chlorinated solvents at the OU-4 site by construction of a Permeable Reactive Barrier Wall in November 1998. It is requested that this information be referenced in the executive

summary and that the conclusions and recommendation on page ES-3 should be reflective of the current decisions at the site.

Response a: Agreed. Reference to the installation of a permeable reactive barrier wall will be made in the executive summary and in Section 6. A brief analysis of the potential benefits and disadvantages of a permeable reaction wall was given in Section 6.2.4 of the TS report. The conceptual purpose of a reactive wall is to degrade contaminants before they can enter into Long Branch Creek. A reactive barrier wall is not intended to treat the source LNAPL at the site. Therefore, groundwater contamination may persist for decades, although mitigated by the wall before entry into Long Branch Creek. AFCEE continues to recommend source delineation and treatment and RNA with LTM as the preferred remedial alternative.

Comment b: The present status of the site is to monitor the effectiveness of the reactive wall and to allow natural attenuation and phytoremediation to address the contamination downgradient of the wall. The base is conducting additional sampling to evaluate the current state of DRO contamination and also to make a decision on the deeper chlorinated solvent plume that could potentially go under the reactive wall.

Response b: Reference to the present status will be made in the executive summary and in Section 6.

Comment c: Other cleanup systems may be incorporated as result of this investigation. The AFCEE study might reference this work and potential impact on the recommendations, although it is understood that the AFCEE study was accomplished for a specific purpose.

Response c: Without knowledge of the specific cleanup systems being considered by Shaw AFB, Parsons ES cannot assess potential impacts to the remediation period and LTM program. Conversations with Mr. Rick Roller, 20 CES/CEV, Shaw AFB indicates that potential future remediation systems would apply to the diesel range organic (DRO) plume of the northeast/east plume lobe. The selection of a treatment technology for the DRO plume will not be determined until after an additional site investigation is performed. Groundwater modeling would be the most useful tool for assessing the impacts of additional remedial systems on the DRO plume once additional groundwater data is gathered. However, additional groundwater modeling is beyond the scope and schedule of the current project. Parsons ES recommends that the impacts of additional remedial systems be evaluated in other reports.

If you have any questions or comments regarding the response to comments, please do not hesitate to contact Mr. Bruce Henry or Mr. Todd Herrington at (303) 831-8100.

Sincerely,

PARSONS ENGINEERING SCIENCE, INC.

Bruce M. Henry
Project Manager

Enclosures